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PGE Surficial Geochemistry Case Studies Project: Lake Nipigon Region Geoscience Initiative

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PGE Surficial Geochemistry Case Studies Project: Lake Nipigon Region Geoscience Initiative

by

P.J. Barnett and R.D. Dyer

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Miscellaneous Release—Data 154

Surficial Geochemistry Case Studies Project Digital Data Set, Lake Nipigon Region, Northwestern Ontario

by R.D. Dyer and P.J. Barnett.

This digital data release, produced by the Ontario Geological Survey as part of the Lake Nipigon Region Geoscience Initiative (LNRGI), contains surficial geochemical, lithogeochemical and indicator mineral data from the northwest Nipigon Embayment collected during the 2003 and 2004 field seasons. The data were released to complement Open File Report 6167 (this report). The geochemical data set comprises the results of analyses of soil, rock, stream sediment, lake sediment, peat and water for over 50 elements, and includes major oxide, trace element, and assay data from the analysis of 86 samples collected from Nipigon diabase sills. The mineral indicator data set includes platinum group element indicator minerals, kimberlite indicator minerals (KIM), metamorphic/magmatic massive sulphide indicator minerals (MMSIM® [1]) and gold grains recovered from till and modern alluvium samples. Magnetic susceptibility data for all rocks collected are also included. All geochemical quality control data from field duplicates, analytical duplicates, certified reference materials and blanks are included in separate files. The data, and associated documents, are available in Microsoft® Excel 97 (*.xls*) and ArcView® shapefile (*.shp*), and Adobe® Acrobat® (*.pdf*) formats on one CD-ROM.

This MRD is available separately from this report.

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[1] MMSIM is a registered trademark of Overburden Drilling Management Limited, Nepean, Ontario.

Abstract

This report summarizes field investigations into the properties, distribution and history of surficial sediments as they pertain to glacial (physical) and chemical (hydromorphic) dispersal of platinum group elements (PGEs) within the glaciated landscape southwest of Lake Nipigon. It discusses the effects of soil development on the physical and chemical properties of the parent material and the hydromorphic dispersal of metals (Au, Cu, Ni, Cr, Co, Pd, Pt) associated with PGE mineralization within the landscape. For the present study, 5 case study areas were selected. Two areas, Lac des Iles and Tib Lake, contain known point-source PGE mineralization, whereas 3 additional sites, Cheeseman Lake, Circle Lake and Tarrison Lakes, contain drainage catchments of lakes that contain anomalous levels of PGEs in bottom sediment. Surficial media sampled included rock, till, sand, soils, stream sediment (organic and inorganic), lake sediment, peat and waters from various sources.

The Surficial Geochemistry Case Studies Project in the Lake Nipigon Region was conducted under a contract agreement between the Ontario Geological Survey and the Ontario Prospectors Association (OPA) for the Lake Nipigon Region Geoscience Initiative (LNRGI). This initiative is operated by the Ontario Prospectors Association (OPA) and funded through an agreement with the Northern Ontario Heritage Fund Corporation (NOHFC). The overall goal of the project is to evaluate, develop and recommend cost-effective strategies and sampling methodologies for PGE exploration using various surficial media.

The distribution of surficial sediment in each case study area is displayed on 1:50 000 scale maps. There are indications from all but one case study area (Circle Lake) of multiple ice flow directions, however, only one till, related to the last ice flow direction, is commonly preserved at all case study areas. Exposures of multiple till layers or interbedded till and stratified sediments are common particularly on the down ice flow direction of bedrock knobs and ridges (lee-side cavity fills) and do not necessarily indicate multiple glaciations or ice flow directions.

Large proglacial lakes inundated all but the highest regions of the case study areas. The Lac des Iles and Tib Lake areas were partly submerged by the waters of glacial Lake Agassiz and the Tarrison Lakes area was entirely flooded. The Cheeseman Lake area was partly submerged by glacial Lake Minong of the Lake Superior basin and Circle Lake case study area was entirely submerged by this lake and some of its ancestors. The landform referred to as the Kaiashk Interlobate Moraine probably formed initially within a conduit beneath the glacier (esker). Then, as the margins of the Laurentide Ice Sheet continued to recede, it continued to form in a large proglacial lake along the margin of a heavily crevassed ice lobe.

Deep-water conditions caused washboard moraines (grounding line fans) to be formed along the receding ice margin particularly in the Circle Lake area. Composed of a variety of sediment types including subglacial lodgement till and flowtills, the washboard moraines may provide till sampling sites in areas where till is scarce. Glaciolacustrine sediments deposited within these proglacial lakes can hinder mineral exploration studies using till, by affecting sample location, density and sampling procedures.

This report contains a number of observations and recommendations to assist PGE exploration in glaciated terrain. These focus on the use and interpretation of lake sediment data and appropriate methods for follow up of lake sediment anomalies. In general, a prudent exploration strategy for PGE mineralization includes targeting the associated metals (Cu, Ni, Cr) to vector to prospective ground prior to detailed work involving the determination of PGEs and/or indicator minerals in surficial media. Relative to the metals copper and nickel, the PGEs have significantly lower initial concentrations (ppb levels), are much less mobile in the surficial environment and are less reliably determined at the laboratory (poorer reproducibility in part due to the classic "nugget effect" and higher potential for contamination).

Over Archean terrain, there is often excellent geochemical contrast between the PGE target rock type (mafic to ultramafic) intrusive and surrounding rock type (e.g., granitic rocks). This geochemical contrast is mirrored in the geochemistry of most surficial media sampled during this project. Over Nipigon sills, the geochemical contrast is much weaker for copper, palladium and gold due to a relatively high background in the sills. Readily weathered (and locally intensely weathered) diabase results in an enhanced (apparently "anomalous") geochemical signal for copper and palladium. "Seagull"-type intrusions share similar weathering characteristics, therefore, explorationists need to focus on the geochemical differences between the diabase sills and the mafic to ultramafic intrusive rocks of interest. The results of stream water sampling show that the Seagull and Disraeli intrusions are imparting a unique signature (e.g., Cr, Ni and Mg) to the surrounding landscape, particularly in contrast to the surrounding ubiquitous (and often difficult to distinguish) Nipigon sill rocks.

Well-defined geochemical dispersal trains were observed in sample results of C-horizon till and heavy mineral concentrates of the till, particularly at Lac des Iles, where sampling density was sufficient. Dispersal trains for PGEs were found to be commonly short, however, the trains of associated elements such as nickel and copper are much larger and provide a much bigger target area for mineral exploration.

The behaviour of nickel in the soil environment is similar to that of platinum and can be used as a proxy for geochemical exploration in most settings. In areas of elevated pH, nickel does not appear to be as mobile as platinum and, therefore, their pathways through the soil environment diverge. The behaviour of copper in the soil environment is similar to that of palladium with respect to relative mobility.

Property-scale geochemical exploration methods for PGE-bearing deposits should include media which target hydromorphically dispersed nickel and copper.

Platinum Group Element Surficial Geochemistry Case Studies Project, Lake Nipigon Region Geoscience Initiative

P.J. Barnett[1] and R.D. Dyer[1]

Ontario Geological Survey
Open File Report 6167
2005

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Introduction

This report summarizes field investigations into the properties, distribution and history of surficial sediments as they pertain to glacial (physical) and chemical (hydromorphic) dispersal of platinum group elements (PGEs) within the glaciated landscape southwest of Lake Nipigon (Figure 1). It discusses the effects of soil development on the physical and chemical properties of the parent material and the hydromorphic dispersal of metals (Au, Cu, Ni, Cr, Co, Pd, Pt) associated with PGE mineralization within the landscape. For the present study, 5 case study areas were selected. Two areas, Lac des Iles and Tib Lake, contain known point-source PGE mineralization, whereas 3 additional sites, Cheeseman Lake, Circle Lake and Tarrison Lakes, contain drainage catchments of lakes that contain anomalous levels of PGEs in bottom sediment. Surficial media sampled included rock, till, sand, soils, stream sediment, lake sediment, peat and waters.

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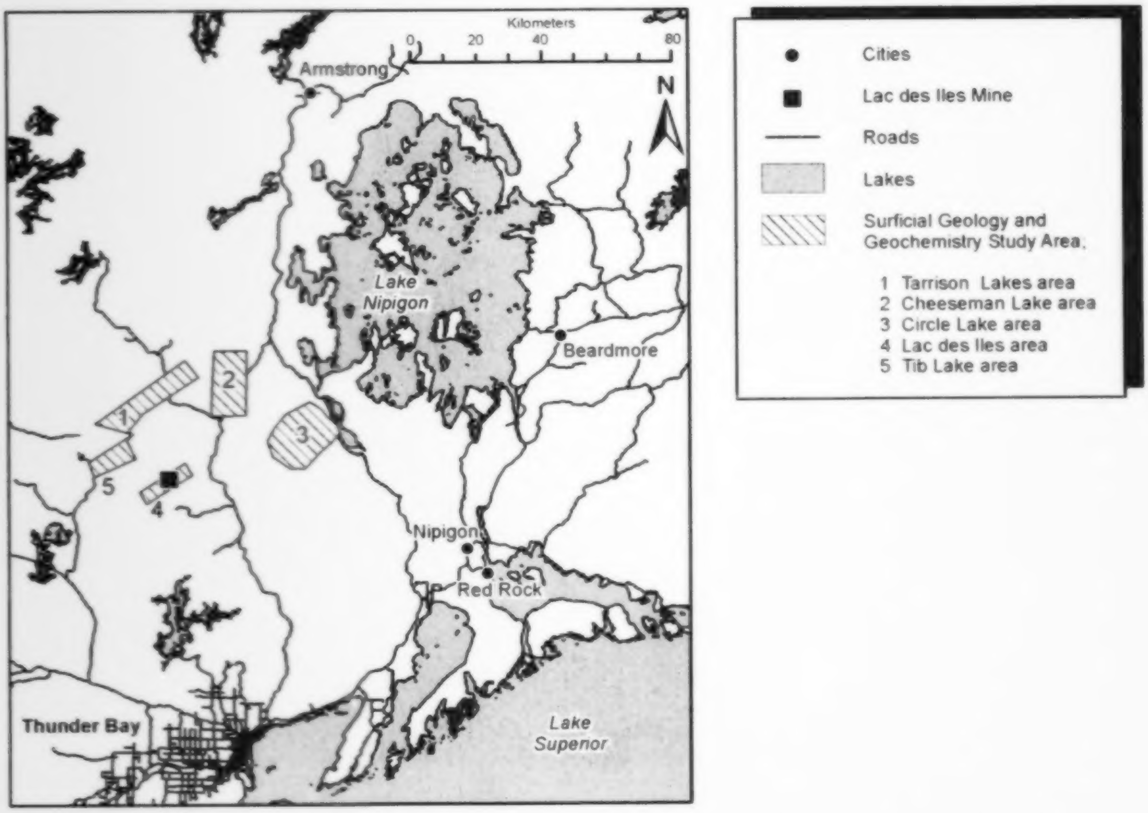

Figure 1. Location of the case study areas, Lake Nipigon Region Geoscience Initiative surficial geochemistry and mapping project.

The report includes discussions on the origin of the landscape and surficial materials and the types and properties of soils that have formed. It discusses pathways for the dispersion of PGEs and associated elements through the environment in the various case study areas. Five maps of the distribution of surficial sediments, at a scale of 1:50 000, are included with this publication.

The majority of field work for this project was completed between July and September during the 2003 field season. For the most part, field work was based out of the Lac des Iles mine site and, for the last 3 weeks of the 2003 season, from the Ministry of Natural Resources base at Rinker Lake. Access to the case study areas was accomplished by a combination of 4x4 trucks, all-terrain vehicles (ATVs), boats and on foot. Approximately 5 hours of helicopter time was used to obtain infill and verification lake sediment and water samples from 4 of the case study areas. During the 2004 field season, additional sampling and check sampling of various surficial media was completed over a period of approximately 5 weeks. Preliminary observations and findings have been published as several *Summary of Field Work* articles (Dyer and Barnett 2003; Barnett 2004; Dyer 2004).

This document forms the final project report and complements a digital data release (Miscellaneous Release—Data (MRD) 154: Dyer and Barnett 2005). The digital data release includes 1) the results of analysis of soils, rock, stream sediment, lake sediment, peat and water for over 50 elements, determined by inductively coupled plasma mass spectrometry (ICP–MS), instrumental neutron activation analysis (INAA) and fire assay–inductively coupled plasma mass spectrometry (FA–ICP–MS); 2) indicator mineral data set including PGE indicator minerals, kimberlite indicator minerals (KIMs), metamorphic/magmatic massive sulphide indicator minerals (MMSIM®[2]) and gold grains recovered from till and modern alluvium samples; and 3) major oxide, trace element, and assay data from the analysis of 86 samples collected from Nipigon diabase sills.

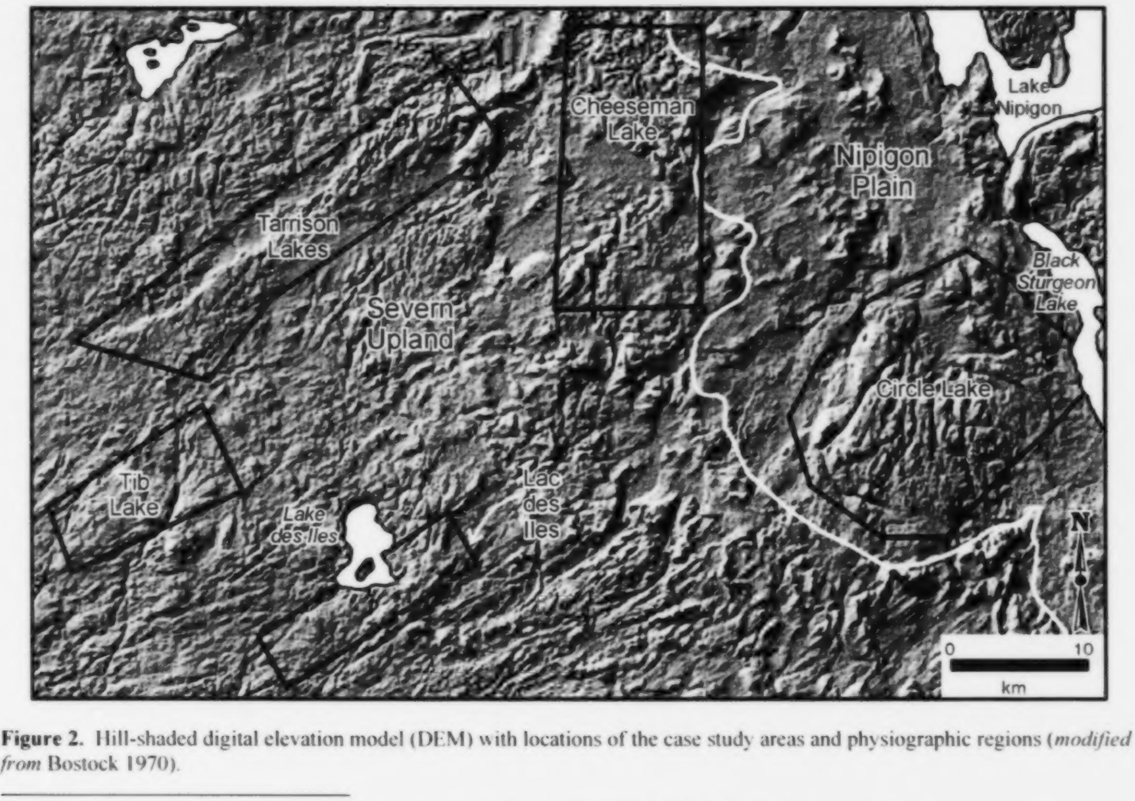

Figure 2. Hill-shaded digital elevation model (DEM) with locations of the case study areas and physiographic regions (*modified from* Bostock 1970).

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Background

REGIONAL GEOLOGICAL SETTING

The region encompassing the case study areas, located on the Canadian Shield, is an irregular, subdued, gently rolling, bedrock-dominated terrain underlain by Precambrian igneous and metamorphic rocks. The area immediately southwest of Lake Nipigon, however, is not typical shield terrain (Figure 2). This area has been referred to as the Nipigon Plain by Bostock (1970) and "is formed on nearly flat-lying Proterozoic gabbro sills and sediments surrounding Lake Nipigon" (Bostock 1970, p.16). Combined past tectonic activity, differential weathering and glacial and/or glacial meltwater erosion of the Proterozoic sills and Sibley Group metasedimentary rock surfaces has produced a unique landscape of buttes, mesas and steep-walled valleys along the margins of the Nipigon Plain. To the west, beyond the extent of the sills, in the area underlain by Archean igneous and metamorphic rocks, more typical Shield terrain is prevalent.

Relief over the entire region exceeds 285 m. Local relief in areas of Archean rocks is commonly between 15 and 45 m. Along the eroded edges of sills that surround the Nipigon Plain, relief can exceed 90 m. Local relief of higher than 90 m also exists along parts of the "Kaiashk Interlobate Moraine", a large ridge composed primarily of sand and gravel that extends across the area.

The Nouveau Québec (Labrador) Sector of the Laurentide Ice Sheet last glaciated the area during the Wisconsin Episode (formerly the Wisconsinan Stage). However, influence of the Keewatin Sector or combined Keewatin and Nouveau Québec Sector (Hudson dome (?), Dyke and Prest 1987) occurred along the northern margin of the region. During deglaciation, large, ice-contact glacier-fed lakes fronted parts of the ice margin (glacial lakes Agassiz and Minong) where the interactions of the glacier with the glacial lakes controlled depositional environments and, hence, the distribution and types of landform, origin (glacial, glaciofluvial or glaciolacustrine), material type and sediment distribution. Elsewhere, particularly at higher elevations, a subglacial landscape is preserved across the region.

BEDROCK GEOLOGY

The study area contains rocks of the Superior Craton and the Southern Province (Figure 3). Major geological subdivisions include the Wabigoon and Quetico subprovinces (Blackburn et al. 1991; Williams 1991), the Proterozoic Sibley Group and Nipigon diabase sills (Sutcliffe 1991).

Milne (1964), Pye (1965, 1968), Kaye (1967a, 1967b, 1969) and Coates (1969, 1972) conducted early mapping in the area. Sage (1998) re-evaluated this early work. Sutcliffe and Sweeny (1986), Smith and Sutcliffe (1987), and Sutcliffe and Smith (1988) concentrated mapping efforts on the Lac des Iles and Tib Lake intrusions. Hart, MacDonald and Lepine (2001a, 2001b) and Stone et al. (2003, 2004) have completed the most recent mapping in the Lac des Iles and Garden Lake areas. Bedrock maps and reports by Hart and McDonald, encompass the 5 surficial case study areas (Hart and Préfontaine 2004; Hart and Magyarosi 2004; MacDonald 2004; McDonald et al. 2004a, 2004b; MacDonald, Tremblay and Easton 2004, 2005; MacDonald and Tremblay 2005; MacDonald, Tremblay and ter Meer 2005a, 2005b; MacDonald et al. 2005).

Metasediments, paragneisses, migmatites and granites are the dominant rocks of the Quetico Subprovince in the Nipigon region. Granodiorite to granite intrusions form the inter-greenstone belt parts of the Wabigoon Subprovince and ultramafic to intermediate rocks, with minor felsic rocks, comprise the supracrustal rocks of the Bo Lake–Heaven Lake and Lac des Iles greenstone belts (Dyer and Russell 2002). The Lac des Iles and Tib Lake intrusions are ultramafic intrusive rocks. Diabase, in the form of sills and dikes, is the dominant rock type in the Nipigon Embayment. They overlie Sibley Group sedimentary rocks that crop out or subcrop within the southern part of the Nipigon Embayment. Based on geophysical data, the greenstone belts to the east of Lake Nipigon have been traced beneath these diabase and sedimentary units and appear to be part of the eastern Wabigoon region (Blackburn et al. 1991).

Much attention has focussed on the PGE potential of the ultramafic intrusions in the study area. Pye (1965) was the first to map the intrusive bodies followed by a more detailed study by Sage (1998). Several others have conducted follow-up work including Sutcliffe and Sweeny (1986); Smith and Sutcliffe (1987); Brugmann and Naldrett (1988); Sutcliffe and Smith (1988); and Edgar and Sweeny (1991). Extensive exploration by Boston Bay Mines–Madeleine Mines Ltd (now North American Palladium Ltd.) led to the development of the Lac des Iles platinum group mineral mine, the only producing platinum-palladium mine in Canada (Dyer and Russell 2002).

The Lac des Iles complex consists of a southern ultramafic centre, containing a wehrlite core, surrounded by websterite and gabbronorite cumulates (Brugmann and Naldrett 1988). The northern ultramafic centre contains several cycles consisting of basal dunite to wehrlite cumulate rocks, overlain

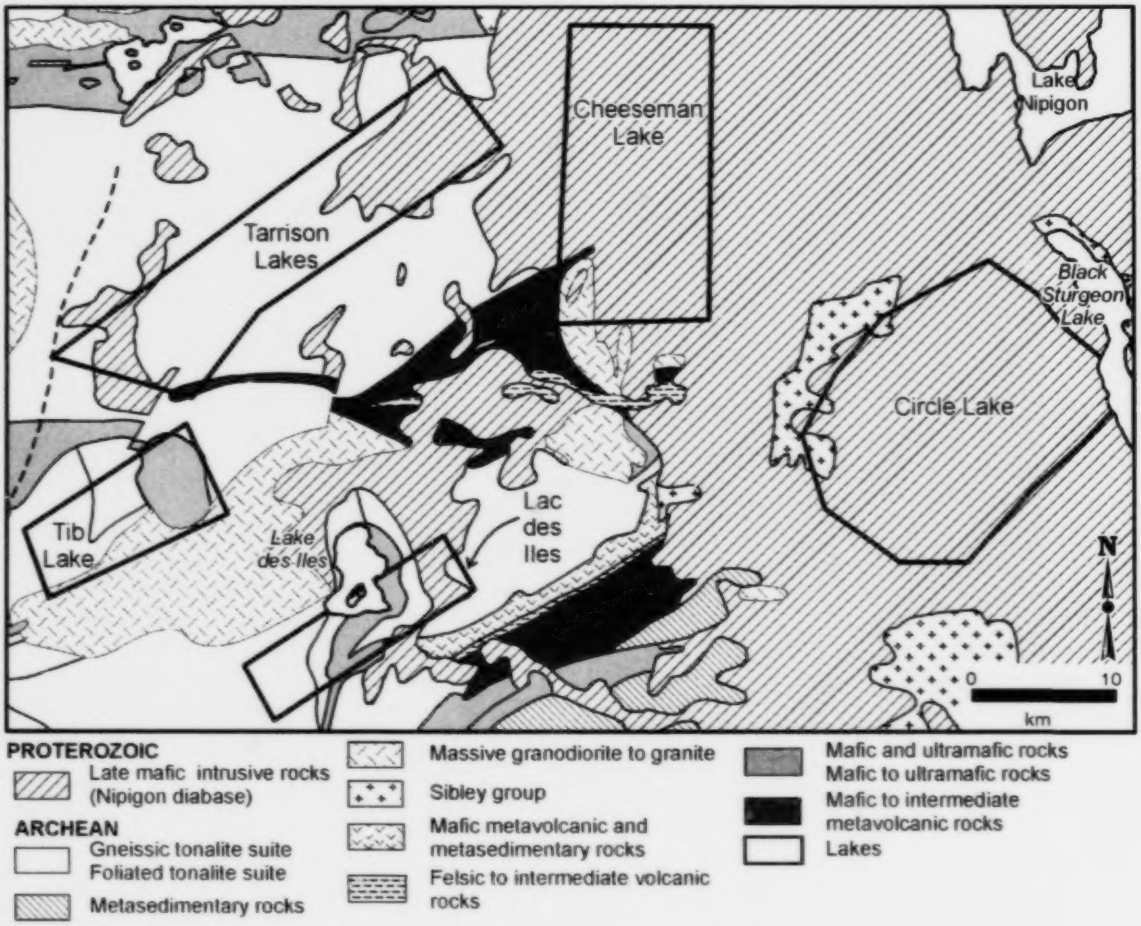

Cheeseman Lake
Lake Nipigon
Tarrison Lakes
Black Sturgeon Lake
Circle Lake
Tib Lake
Lake des Iles
Lac des Iles
N
0
10
km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Gneissic tonalite suite
Foliated tonalite suite
Metasedimentary rocks
Massive granodiorite to granite
Sibley group
Mafic metavolcanic and metasedimentary rocks
Felsic to intermediate volcanic rocks
Mafic and ultramafic rocks
Mafic to ultramafic rocks
Mafic to intermediate metavolcanic rocks
Lakes

Figure 3. Regional bedrock geology map (OGS 2003).

by clinopyroxenite and websterite rocks, and localized gabbronorite. Brugmann and Naldrett (1988) also observed that major and trace element variation reflects zoning of the complex. The centres have been interpreted to result from different parental magmas. Platinum group mineral mineralization is preferentially hosted in the southern ultramafic centre, within the Hybrid zone (Edgar and Sweeny 1991).

The flat-laying Nipigon sills cover most of the northeastern portion of the area. An age of approximately 1108 Ma has been determined for the Nipigon sills and, therefore, were contemporaneous with the initiation of the Lake Superior Midcontinent Rift (Blackburn et al. 1991). Intrusive bodies may represent the loading mechanism that initiated rifting processes (Blackburn et al. 1991). Only minor felsic rocks have been found in association with the sills.

The Nipigon sills are massive bodies that vary in thickness from 150 to 200 m. Internal textural zoning indicates that the sills are single cooling bodies (Blackburn et al. 1991). The Nipigon sills in the area are monotonous in textural appearance and are difficult to distinguish by visual appearance in the field from other discrete mafic to ultramafic bodies (T.R. Hart, OGS, personal communication, 2004). The Nipigon diabase sills are composed of medium- to coarse-crystalline feldspar and pyroxene that should properly be classified as gabbro (Hart and Whaley 2004); however, due to historical reference to these sills as diabase, this usage will be continued in this report.

Several Proterozoic mafic to ultramafic intrusions have been identified within the Nipigon Embayment and are being explored by several mineral exploration companies for platinum group minerals. These include the Disraeli, Seagull and Hele intrusions, located in the southern portion of the western Nipigon Embayment.

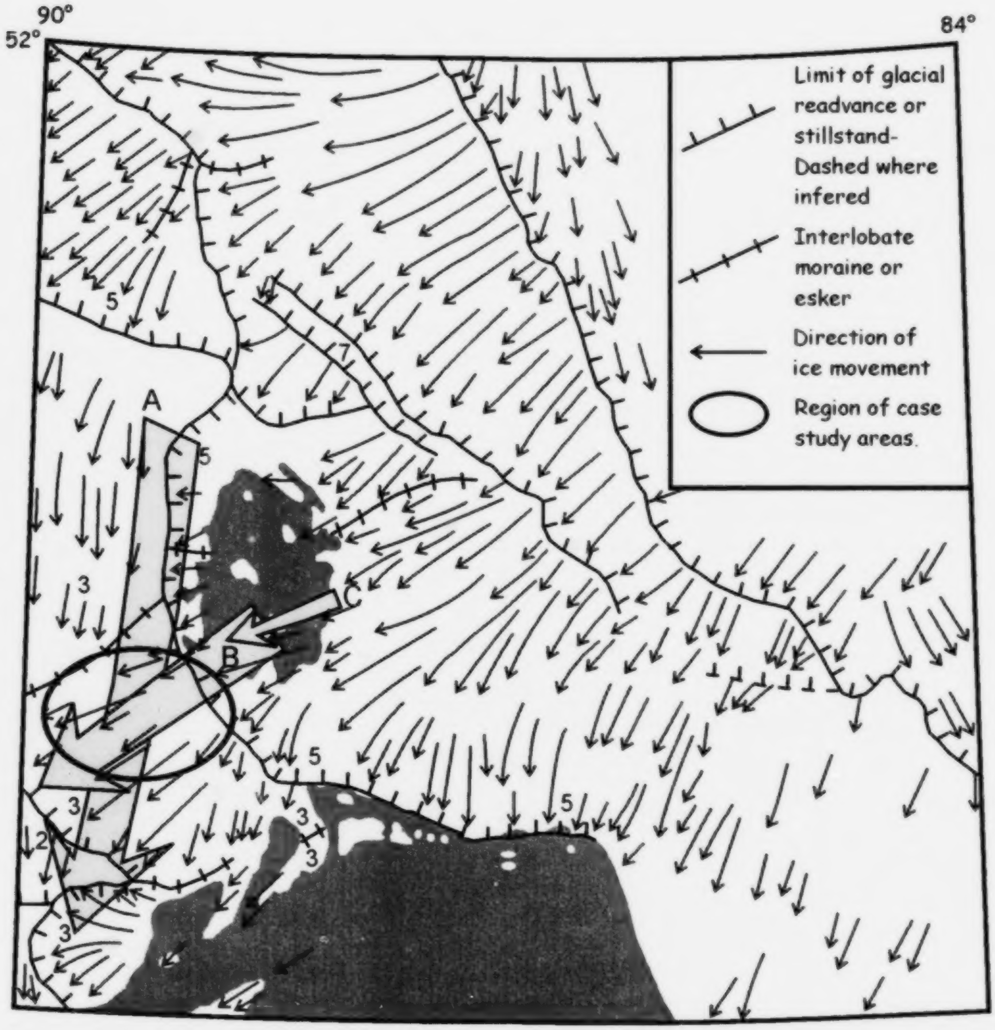
The Sibley Group sediments (1339±39 Ma: Franklin 1978; ≤1450 Ma: Heaman and Easton 2005) contain an unmetamorphosed red-bed sequence consisting of conglomerates, sandstones and shales, that accumulated in a subsiding graben prior to the formation of the Midcontinent Rift (Sutcliffe 1991). Fyon et al. (1991) identified several potential types of mineralization associated with the Sibley Group sediments, including unconformity-related uranium and red-bed copper.

SURFICIAL GEOLOGY AND MINERAL EXPLORATION IN GLACIATED TERRAIN

The surficial (Quaternary) geology of the area south and west of Lake Nipigon has been investigated only at a regional scale despite its importance to the overall understanding of the glacial history of Ontario and, in particular, to mineral exploration in the region using unconsolidated sediments (drift exploration). Regional maps at various scales covering the area include Zoltai (1965a), Sado and Carswell (1987), Barnett, Henry and Babuin (1991) and Sado, Fullerton and Farrand (1994). Zoltai (1965b) described and discussed the formation of some of the major landforms and deposits of the Quetico–Nipigon area. Mollard and Mollard (1981a, 1981b, 1981c, 1983) undertook a terrain analysis of the study area and produced maps of some of the major landforms and material types that occur. Several theses and papers have been written on significant aspects or features of Quaternary age from within the area of interest (Lemoine 1989; Schlosser 1983; Teller and Thorliefson 1983, 1987; Teller and Mahnic 1987).

Zoltai (1965a, 1965b), Elson (1967), Prest (1970), Dredge and Cowan (1989), Barnett (1991) and Sado, Fullerton and Farrand (1994) have summarized regional concepts for the glacial history southwest of Lake Nipigon. There is very little agreement as to the details of the glacial sequence and timing of events. Deposits in the area probably represent ice movement during the Michigan Subepisode (Late Wisconsinan), however, they may reflect ice cover during the entire Wisconsin Episode or approximately the last 100 000 years. The Laurentide Ice Sheet flowed southwestward across the region during its maximum extent about 20 000 years ago. During deglaciation and possibly during initial ice movement into the area, ice flow direction was controlled, on a regional scale, by topography. During these times, ice flow followed broad topographic lows, especially the Great Lakes basins and most likely Lake Nipigon, producing lobate ice margins that could possibly behave somewhat independently of the main ice mass (Figure 4).

Prest (1970), following the work of Zoltai (1965a, 1965b), suggested that an active ice margin in northwestern Ontario fronted glacial Lake Agassiz during ice margin retreat. It was postulated by Zoltai (1965b) and Prest (1970) that several alternating stages of ice margin retreat and re-advance produced



90°
52°
84°
Limit of glacial readvance or stillstand- Dashed where infered
Interlobate moraine or esker
Direction of ice movement
Region of case study areas.
A
B
C
2
3
5
7

* Numbers relate to ages, glacial phases and moraine:

2. ~ 11 ka Brule Creek Moraine
3. ~ 10 ka Marks and Dog Lake Moraine
3,4. ~ 9.8 ka Kaiashk Interlobate Moraine
5. ~ 9.5 ka Nipigon Moraine

Figure 4. Regional ice flow movement and location of moraines (Sado, Fullerton and Farrand 1994). Large grey arrows indicate ice flow directions directly affecting the case study areas (A, B, C – oldest to youngest).

most of the major moraines in northwestern Ontario. It has been suggested that the Marks, Mackenzie and Dog Lake moraines formed at about the same time, about 10 000 years ago (Burwasser 1977; Drexler, Farrand and Hughes 1983). With further ice margin recession and a suggested major re-advance, the Lac Seul moraine formed (Prest 1970). Zoltai (1965b) suggested that this ice margin formed the northern part of the Kaiashk Interlobate Moraine that occurs within the Tarrison Lakes case study area (*see* Figure 4).

Prest (1970) suggested that with further ice margin retreat, the Sioux Lookout and Whitewater moraines formed west of Lake Nipigon. These events were followed by a westward advance in the Lake Nipigon basin that produced the Nipigon Moraine along the west and southern side of the lake (Zoltai 1965a, 1965b). Prest (1970) suggests that only the northern part of this moraine formed following the Whitewater Moraine and that the southern part is older. Several other moraines east of the Nipigon Moraine were identified by Zoltai (1965a, 1965b) in the Lake Nipigon basin that appear to be younger than the Nipigon Moraine. The Nakina Moraines that are located along the northeastern edge of the basin mark the last significant ice margin positions to affect the region. To further complicate the history is the suggestion that glacial Lake Agassiz waters drained catastrophically into the Lake Nipigon basin several times during deglaciation of the Lake Nipigon basin (Teller and Thorliefson 1983, 1987). These proposed events are based on the occurrence of several coarse-grained deposits associated with the large deep steep-walled valleys that are present throughout the region. However, an alternative explanation for the development of these features and others in this landscape, is that subglacial floods may have created them. This hypothesis is based on the similarities of this landscape to that of the Channelled Scablands of eastern Washington State (Baker et al. 1987). If the latter is true, then the types of sediments and their distribution would be different than that expected for a classical subglacially formed landscape. Outflow from glacial Lake Agassiz may, however, have reoccupied some of the channels carved by the subglacial meltwater flood(s).

The complex and still poorly understood deglacial history of the southwestern Nipigon basin does not make drift exploration easy. The events and features discussed above could have resulted in many areas having multiple directions of ice movement due to the shifting of ice centres through time. Unravelling such history requires linking evidence of ice movement to specific tills (*see* Figure 4). Determining the history of meltwater and ancestral lakes in the study area is also very important to interpret the results of drift exploration programs.

Several models of glacial dispersal have been presented in the past, but most build from the pioneering work of Dreimanis (1982, 1989, 1990), Dreimanis and Vagners (1971), Shilts (1975, 1976) and Boulton (1971, 1976, 1978, 1984, 1996). Several articles outline hydromorphic dispersal models, but most build from the work of Bradshaw (1975). A series of papers (Kujansuu and Saarnisto 1990; McClenaghan et al. 2001) provide excellent summaries of some of the latest thinking and ideas on both of these topics.

Deposits of the Laurentide Ice Sheet have been a hindrance to mineral exploration in the Canadian Shield for many years. In areas where the cover of Quaternary sediments is very thin and discontinuous, bedrock maps and mineral exploration can proceed in traditional ways. However, in areas of more continuous drift, where the cover of Quaternary sediments is thick, other methods must be used. In these areas, indirect mineral exploration methods such as geophysical and geochemical surveys and drift prospecting must be employed.

Classic techniques for geochemical surveys developed in non-glaciated areas do not work well in Ontario. Residual soils are rare and, if present, are very thin and poorly developed. Most soils in Ontario are developed on transported parent materials, the products of glacial incorporation and transport with final deposition by ice, water or wind. The composition of glacial deposits and till in particular, however, can be very helpful in finding mineral resources.

Till is a primary product of glacial erosion and deposition. This, combined with its widespread distribution, makes it an ideal medium to sample. The glacial debris of which till is composed is the accumulation of all the various rock types and sediments that the glacier has overridden. All components of till reflect the geology up-ice from a sample site. The concentration of any rock or mineral type or element in till decreases away from its source area (Figure 5a). This decline in concentration approximates a negative exponential curve (Shilts 1976).

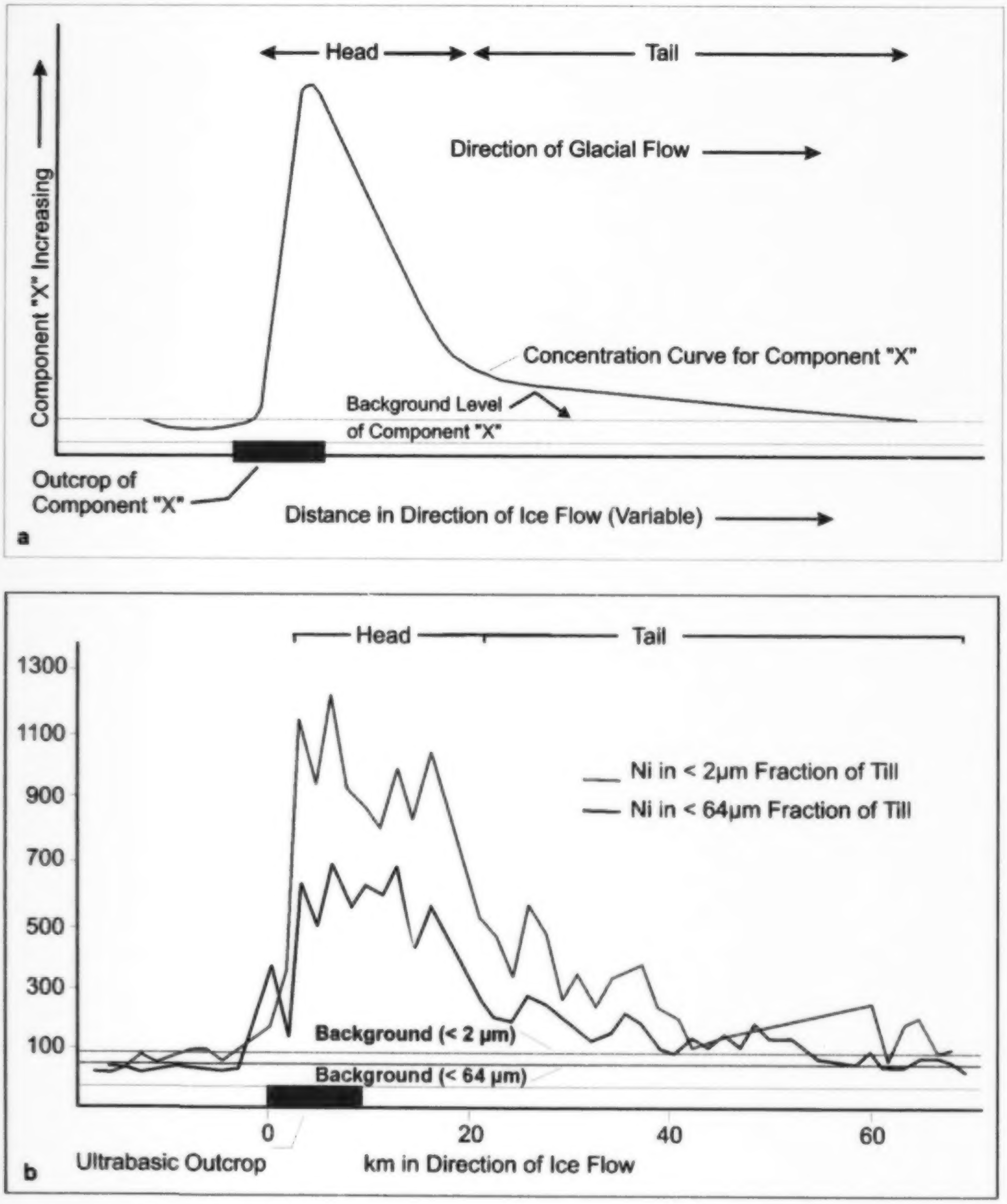


Figure 5. a) Idealized model of glacial dispersal train; and b) a regional dispersal curve of nickel content in till samples, Thetford Mines area, Quebec (*modified from* Shilts 1976).

The body of till which is enriched in a certain rock, mineral, or element is called a dispersal train or plume, and is often ribbon or fan shaped (DiLabio 1989). Lateral contacts of the dispersal train are often sharp, with concentrations of the enriched material dropping off quickly to background levels outside the boundaries of the dispersal trains. At the up-ice end or head of the dispersal train concentrations are the highest. The tail of the dispersal train, which exhibits an exponential decline in concentration, is usually many times larger than the head and provides a much bigger target area than the head of the train or the original source. The main objective of a till geochemistry survey for mineral exploration is to simply detect the tail of a dispersal train, follow it back up-glacier to its head, and then locate its source (Coker and DiLabio 1989).

Dispersal trains of distinctive boulders, minerals, major and/or trace elements can and have provided clues to the location of mineralized bedrock beneath the cover of Quaternary sediments (Shilts 1976, 1984; Bolviken and Gleeson 1979; DiLabio 1989; Coker and DiLabio 1989). An idealized model of a glacial dispersal train that could apply to large parts of the Canadian Shield in Ontario, where only one till overlies an irregular bedrock surface, is illustrated in Figure 5b. It should be noted that the position of the source in relation to topography and ice-flow direction alters the shape and extent of the dispersal train. In areas with significant local relief, the dispersal train may be trapped in valleys, be broken into disjointed segments, or even be truncated (Coker and DiLabio 1989).

In the preliminary stage of mineral exploration programs, sampling densities in the order of one till sample per square kilometre may suffice (Coker and DiLabio 1989) to detect dispersal trains derived from individual rock units, distinctive belts of rock, or mineralization. Samples designed to locate the heads of dispersal trains are usually collected with spacings on the order of tens to hundreds of metres (Coker and DiLabio 1989).

Fundamental knowledge of glacial deposits and their distribution, and the glacial history of the region of interest are essential for a successful drift prospecting program. Particular attention must be paid to determining the glacial stratigraphy of the program area and the local and regional patterns of ice flow.

Postglacial weathering and soil formation may result in the mobilization of elements in groundwater and soil water. The elements in the dispersal train may be concentrated in particular soil horizons or spread downslope altering the original shape of the dispersal train (Figure 6). Klassen (2003) has described 5 geochemical profile types that developed during soil formation in naturally metal-rich terrains of eastern Canada (Figure 7).

The geochemistry of stream and lake sediments can also be used over large areas to characterize the geochemistry of the surface materials (Coker and Shilts 1979; Fortescue 1980). Geochemical anomalies found in these types of sediment samples, having been derived from the erosion of rock, till and other proglacial sediments, are more difficult to use to interpret source area, however, areas for follow-up surveys can be identified.

SURFICIAL GEOCHEMISTRY

Available surficial geochemical data over the Nipigon Embayment rocks consists mostly of regional lake sediment data sets completed by the Ontario Geological Survey (OGS) and Geological Survey of Canada (GSC). Such lake sediment surveys to assist mineral exploration have been carried out since the 1970s over glaciated parts of Canada. The abundance of lakes and their propensity to accumulate metals derived from the surrounding landscape make this technique very useful for mineral assessment, particularly for remote, inaccessible areas. Several excellent reviews detailing the use of lake sediment geochemistry for mineral exploration and environmental studies include Coker, Hornbrook and Cameron (1979), Friske (1991) and Cook and McConnell (2001).

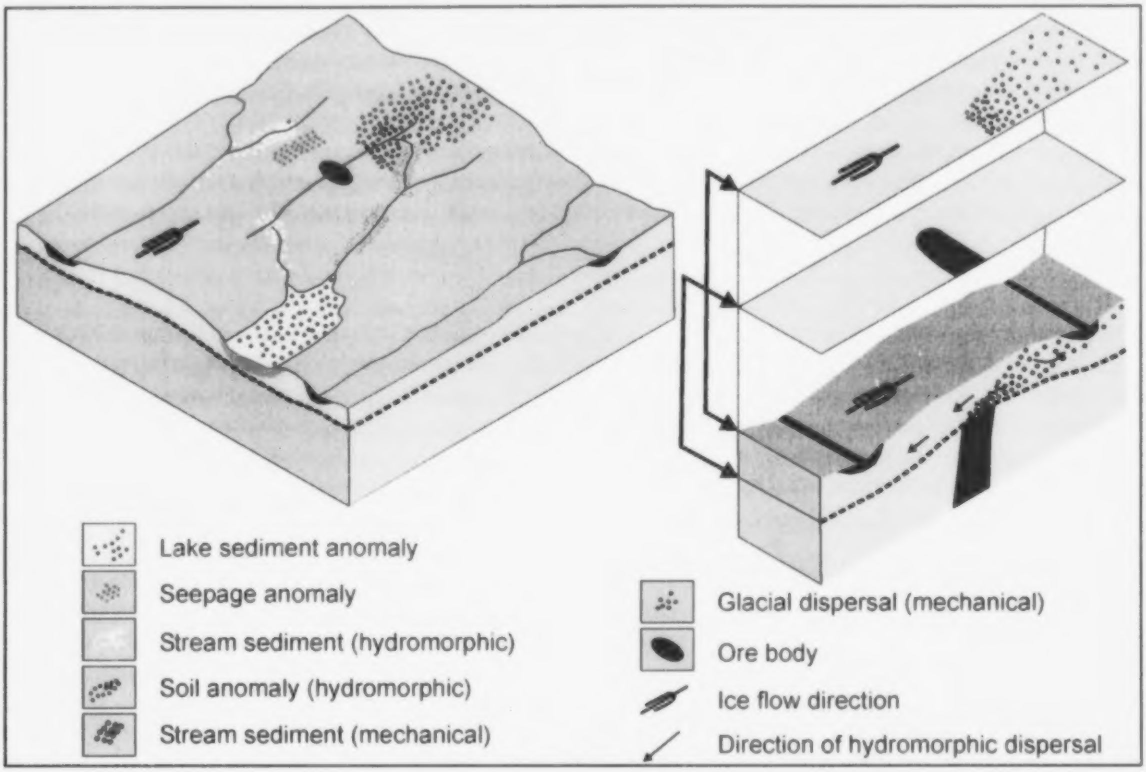

Lake sediment anomaly
Seepage anomaly
Stream sediment (hydromorphic)
Soil anomaly (hydromorphic)
Stream sediment (mechanical)
Glacial dispersal (mechanical)
Ore body
Ice flow direction
Direction of hydromorphic dispersal

Figure 6. Idealized model of geochemical dispersal (*after* Bradshaw 1975).

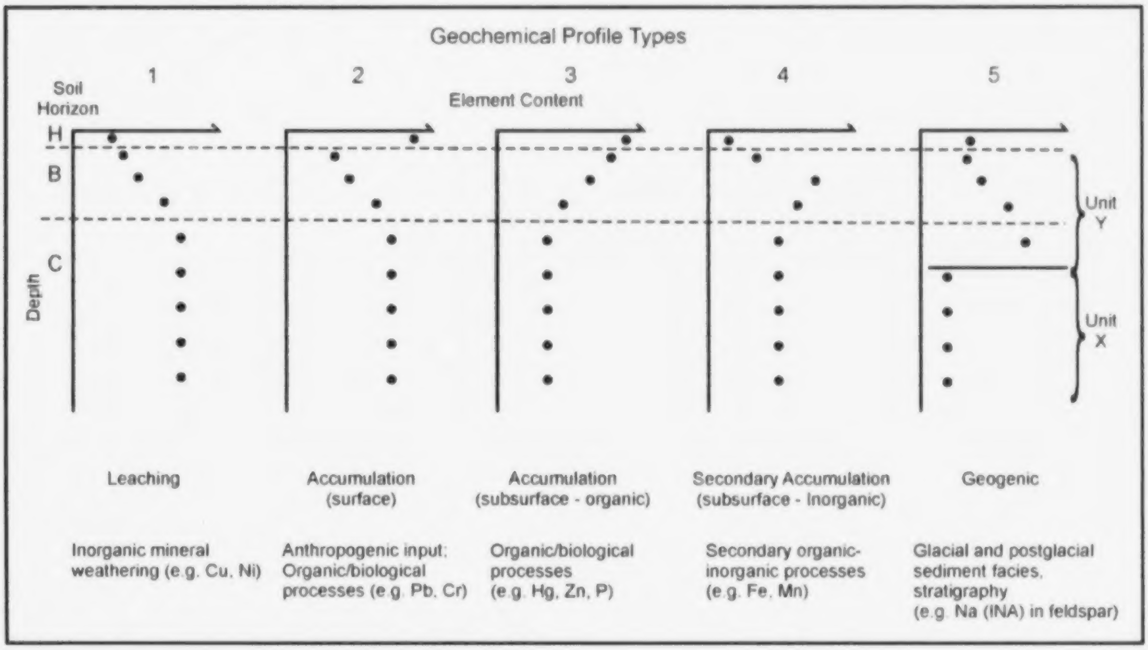

Geochemical Profile Types
1
2
3
4
5
Soil Horizon
Element Content
H
B
C
Depth
Unit Y
Unit X
Leaching
Accumulation (surface)
Accumulation (subsurface - organic)
Secondary Accumulation (subsurface - Inorganic)
Geogenic
Inorganic mineral weathering (e.g. Cu, Ni)
Anthropogenic input; Organic/biological processes (e.g. Pb, Cr)
Organic/biological processes (e.g. Hg, Zn, P)
Secondary organic-inorganic processes (e.g. Fe, Mn)
Glacial and postglacial sediment facies, stratigraphy (e.g. Na (INA) in feldspar)

Figure 7. Geochemical profile types (*modified from* Klassen 2003).

Surficial geochemical data over the Nipigon Embayment, until relatively recently, has been sparse. The area south of latitude 49°30′N (essentially the area south of Lake Nipigon) was sampled at a reconnaissance scale during the National Geochemical Reconnaissance (NGR) lake sediment program carried out jointly by the GSC and the OGS during the late 1970s and early 1980s (e.g., Friske et al. 1990). Samples were collected at a relatively low density of 1 sample per 13 km^2. Under the same program, infill sampling and analysis for precious metals (including PGEs) was carried out in more detail over 4 smaller areas, including the Lac des Iles intrusion (Friske, McCurdy and Cook 1990). The first detailed lake sediment survey completed by the OGS centred on the Garden–Obonga lakes area, but overlapped onto Nipigon Embayment rocks (Jackson and Dyer 2000; Ontario Geological Survey 2000a). This was followed up by almost complete coverage of the northwestern, western and southern parts of the Nipigon Embayment during the Operation Treasure Hunt (OTH) program (Ontario Geological Survey 2000b; Dyer and Russell 2002). The OTH surveys included analysis for PGEs and archived pulps from the OGS Garden–Obonga lakes area survey were re-analyzed for the same.

The combined results of these lake sediment surveys have demonstrated that the Nipigon Embayment diabase rocks are contributing significant levels of several metals, in particular copper, to the lake basins. For explorationists, one of the most intriguing aspects of these surveys has been the relatively high levels of palladium and platinum that are present in many of the lakes. In many areas, the levels of PGEs in lake sediment are highly disproportionate (anomalous) compared to the background levels typical of the underlying Nipigon diabase bedrock; these anomalies have attracted exploration attention, which, in many cases, have yielded no clear answer as to the source of the anomalous metal levels. This is one of the issues that the surficial case studies project was meant to address. However, the findings and recommendations of this current project are broader in scope and can be applied to other areas beyond the Nipigon Embayment. Another recent (concurrent) study under the Ontario Mineral Exploration Technologies (OMET) program has focused on palladium exploration over Archean terrane adjacent to the Nipigon Embayment (Hattori and Cameron 2005). Together with this document, these studies serve to fill a knowledge gap concerning the use of surficial media for exploration on and near the Nipigon Embayment.

Rationale for the Selected Case Study Areas

LAC DES ILES CASE STUDY AREA

The Lac des Iles case study area has been the focus of previous case studies attempting to understand the glacial and hydromorphic dispersal of PGE minerals (Searcy 2001; Hattori and Cameron 2004). The area contains known occurrences of PGE mineralization, including the Lac des Iles PGE mine, and has associated lake sediment anomalies. The area was first examined using lake sediment sampling during the NGR program, the samples of which were later re-analyzed for PGEs and gold (Friske et al. 1990). The OGS lake sediment survey (Dyer and Russell 2002) covered the area at a higher density, but, due to the development of the Lac des Iles Mine and the presence of tailings, it was not possible to sample near the high-grade area around the Roby zone. The lack of a signature in this area was likely due to the low density of available sampling sites. However, samples from Shorty Lake, immediately adjacent to the Baker zone, have returned consistent and reproducible levels of PGEs from 2 different laboratories. Down drainage from Shorty Lake to the south is Camp Lake, which also returned anomalous palladium and gold from the OGS 2002 survey. The present study is designed to build on the findings of previous studies.

The Lac des Iles case study area occurs within the southern ultramafic centre of the Lac des Iles Complex. The southern ultramafic centre has a wehrlite core that is centred on Southeast Angle Bay (Sutcliffe 1991). Gabbroic rocks occur south of the lake and host the Pd and Pt mineralization of the Roby zone, the current mine site area. Platinum group element (PGE) mineralization is associated with copper-nickel sulphides. Seven different platinum group minerals have been reported from the area (Dunning 1979; Watkinson and Dunning 1979; Cabri and LaFlamme 1979; Brugmann and Naldrett 1988). Several mineral showings occur within the southern ultramafic centre (Sutcliffe and Sweeny 1986) including the Powerhouse and Baker zones.

The Lac des Iles area is a low to moderate relief bedrock-dominated terrain. Till is the dominant surficial material within the case study area, but is usually thin, stony, sandy and commonly contains discontinuous layers or lenses of sand (Sims et al., unpublished report [undated]). Mollard and Mollard (1981a) mapped an area in the western part of this case study area as hummocky moraine composed of till. This may represent a former ice margin position that, if the interpretation is correct, could have implications for surficial sediment-sampling programs. Sand and gravel (esker) have been mapped along the southern margin of the case study area (Mollard and Mollard 1981a) and a small esker was delineated on the bedrock geology map of Sutcliffe and Sweeny (1986). Ice flow was determined to be to the west-southwest (Sutcliffe and Sweeny 1986; Searcy 2001).

The Lac des Iles case study area appears to be a preserved subglacial landscape except possibly for the western end. In general, it is a good setting for mineral exploration studies using till. With the development of the mine site, however, several bedrock mineral showings are no longer available to study. The Baker and Powerhouse zones have been the subject of previous glacial and hydromorphic dispersal studies (Searcy 2001; Hattori and Cameron 2004). The association with sulphide minerals of nickel and copper (Sutcliffe and Sweeny 1986) allows for the detection of multiple and/or proxy element dispersal patterns in some parts of the case study area.

The case study area is approximately 17 km long in the direction of ice flow and about 4 km wide (*see* Figure 1). Samples of humus and B- and C-horizon soils developed in till were collected, where available, from approximately 50 sites within the case study area. Most of the sample sites were from exploration trenches located in the vicinity of the Baker and Creek zones. Additional till samples were collected both up ice-flow direction and down ice-flow direction of the Mine Block intrusion. Sampling was completed to define the shape and size of dispersal trains. Initially, 5 samples of till were collected for heavy mineral concentrating and analysis. However, after receiving interesting results from the initial 5 samples, 21 additional samples were collected. In addition, sites of previous dispersal studies were visited to evaluate the results and materials that were sampled in order to build on these studies (e.g., Searcy 2001; Hattori and Cameron 2004). Stream water and sediment and organic samples from bogs and swamps were collected in and around the Baker zone. Due to the previous generations of sampling in the area, only 1 additional water body was sampled; shallow and deep sediment were collected from Walters Bog.

TIB LAKE CASE STUDY AREA

The Tib Lake area appears to be a preserved subglacial landscape, ideal for drift exploration studies. The relatively small size of the intrusion and the strong contrast in lithology with adjacent country rock allows for the study of debris entrainment, transport and deposition at a regional scale. The mineral showings, which trend in a north-northwest direction, roughly perpendicular to ice flow, provide an ideal situation to study glacial and hydromorphic dispersal patterns of sulphides and PGE minerals. The positive relationship of nickel, copper and chromium content and the negative relationship of strontium and zirconium content with platinum and palladium (Smith 1991) allows for the detection of multiple and/or proxy element dispersal patterns. However, once in the study area, it was found that conditions were far from ideal. Glaciolacustrine sands cover a large part of the case study area making it difficult to locate till to sample. In addition, leeside cavity fills of sand and gravel occur down-ice flow of some of the main mineral showings preventing the definition of dispersal trains within till associated with the showing.

Although the Tib Lake area has known mineralized showings, no lake sediment anomalies were obtained, except for one gold anomaly (Dyer and Russell 2002). While the main objective of this case study area is to characterize both mechanical and chemical dispersion from known PGE sources, also of interest is ascertaining the reasons why the lake sediment survey did not detect the presence of any PGEs.

The Tib Lake case study area is centred on the Tib Lake intrusion, an Archean layered mafic (gabbro) intrusion, which has also been referred to in the literature as the "Tib Gabbro". The intrusion, some 25 km^2 in area, contains several surface showings with elevated values of sulphides (1 to 5%) and PGEs (Kuhner, Jewelweed and Road occurrences: Houston Lake Mining Inc., http://www.houstonlakemining.com/ (Properties/Tib Lake palladium property/property description) [accessed August 16, 2005]; Smith 1991). Smith and Sutcliffe (1987) completed detailed mapping of the intrusion and Smith (1991) presented information on the geochemistry and petrology of the Tib Lake intrusion.

The Tib Lake area is a low to moderate relief bedrock-dominated terrain with, in general, a thin, discontinuous cover of till. Minor areas of sandy 'outwash" occur in some of the low-lying areas along the margins of the case study area (Mollard and Mollard 1981a) and may possibly be linked to the formation of the "Kaiashk Interlobate Moraine" (Zoltai 1965a, 1965b) that lies to the north. Modification of the sand deposits by wind may have also affected the surficial sediments throughout the case study area. Ice flow direction, based on mapped streamline landforms southwest of the study area (Mollard and Mollard 1981a), is toward the west-southwest.

The case study area is approximately 15 km long in the direction of ice flow and about 6 km wide (*see* Figure 1). Sampling humus and B- and C-horizons developed in till, where available, was the primary goal for the glacial dispersal component of the study. Detailed sampling for the Tib Lake case study area involved the collection of samples near showings, however, this was hindered by the occurrence of thick sands at surface and/or common occurrence of leeside cavity fills down-ice of known showings.

Stream water and sediment and organic samples from bogs and swamps were collected in and around known showings and in areas thought to be equivalent to background. Three lake sediment samples in this area were obtained, 2 along the East Dog River drainage and one to verify the lake that returned an anomalous Au value in the previous OGS lake sediment sampling program (Dyer and Russell 2002).

CHEESEMAN LAKE CASE STUDY AREA

This area contains several multi-element lake sediment anomalies, thus providing a good test area to determine the best exploration follow-up methods to use. It has been mapped as a bedrock-dominated terrain (Mollard and Mollard 1981a) that could be ideal for glacial dispersal studies. The Cheeseman Lake area was specifically targeted for lake-sediment sampling by the OGS in 1998 during the Garden–Obonga lakes area lake sediment survey (Ontario Geological Survey 2000a). This was due to the presence of anomalous levels of gold and copper in 2 lakes identified through the National Geochemical Reconnaissance (NGR) program. The 2 lakes, located to the northeast of Cheeseman Lake, returned very similar results in the 1998 OGS survey. Re-sampling of these 2 lakes again in 2001, once again corroborated the presence of anomalous levels of gold and copper. The 1998 survey also targeted 18 additional lakes in and around the original anomalous lake sites, of which 11 returned anomalous gold and 16 returned anomalous copper levels. During the 2001 survey, 17 of these 18 lake sites were re-sampled, resulting in gold anomalies at 13 sites and copper anomalies at 11 sites.

The bedrock geology underlying the Cheeseman Lake case study area has been mapped as Proterozoic (Keweenawan) diabase sills and dikes. Differential erosion of these rocks has produced a low to high relief bedrock-dominated terrain. In areas of moderate to high relief, a thin discontinuous cover of sandy till is common. Low-lying, low-relief areas are underlain by organic terrain, sands previously interpreted as outwash, and till in ground moraine (Mollard and Mollard 1981a). Minor areas of glaciolacustrine sediments and esker fragments have been mapped marginal to the case study area (Mollard and Mollard 1981a). In the northwest corner of the area, a small part of the Kaiashk Interlobate Moraine occurs.

Based on a hill-shaded digital elevation model and mapping by Mollard and Mollard (1981a), west-southwest-oriented streamlined landforms occur to the east and southwest of the case study area. These may reflect the last direction of ice flow in the area. However, there may have been some ice movement to the south-southwest associated with the formation of the Kaiashk Interlobate Moraine.

The Cheeseman Lake area appears to be a preserved subglacial landscape. However, the areas of high relief may affect the pattern of ice movement locally and also the location and style of deposition of till. This, in combination with the possibility of multiple ice flow directions, may complicate the interpretation of glacial dispersal patterns.

The case study area is approximately 20 km long and about 10 km wide (*see* Figure 1). The regional sampling strategy consisted of sampling humus and B- and C-horizons developed on till, where available, both in the up-ice direction and down-ice of lake sediment anomalies. This was done to characterize the till (regional dispersal patterns) and soil development in the till (hydromorphic dispersal patterns). At 6 of the sample sites, a heavy mineral concentrate sample was collected. Detailed sampling for the Cheeseman Lake case study involved the collection of samples from various media within selected catchment areas. Three anomalous catchment areas and one background catchment area were selected for detailed study. Within each catchment area, stream sediment, water and organic bank samples were collected where streams are about to enter a lake or wetland area. Organic matter from wetlands and wetland water samples were also collected. Humus, B- and C-horizon soil samples were collected around all of the lakes contained in each of the 4 catchment areas.

Due to the excellent corroboration of lake sediment geochemistry between the 1998 and 2001 surveys, only 2 additional lake sediment samples were obtained within this study area. These samples came from 2 sub-basins located on Cheeseman Lake.

CIRCLE LAKE CASE STUDY AREA

This area contains several multi-element lake sediment anomalies, thus providing a good test area to determine the best exploration follow-up methods. The area appears to be predominantly a preserved subglacial environment with minor glaciofluvial and glaciolacustrine components (Mollard and Mollard 1981c). This broad multi-element–multi-site lake sediment anomalous area features values for Pd and Pt that range up to 38.5 ppb and 14.2 ppb, respectively. Highly anomalous Cu (up to 637 ppm) and Ni (up to 100 ppm) characterize many of the anomalous PGE lake sites (Dyer and Russell 2002).

The Circle Lake case study area is underlain primarily by Proterozoic diabase sills with the possible Sibley Group sedimentary rocks exposed in topographically low areas (Coates 1972; Ontario Geological Survey 1991). The terrain conditions in the study area are mapped predominantly as a moderate to low relief bedrock-dominated terrain covered by a thin discontinuous layer of till (Mollard and Mollard 1981a, 1981c). Till, outwash sand and gravel, ancestral lake silt and sand, and organic terrain occur in low-lying plains adjacent to the case study area (Mollard and Mollard 1981a, 1981c). Till in the area varies in texture from a silty sand to sandy silt; the coarser the matrix, the stonier the till (Sims et al.

unpublished). B-horizon soil samples from till contain more silt than C-horizon till samples (Sims et al. unpublished). Former ice-margin positions are located both north and south of the case study area and ice-flow directional indicators are oriented in a radial pattern from south-southwest to west-southwest (Mollard and Mollard 1981a, 1981c; Sims et al. unpublished). The development of postglacial lakes in this area and the proposed Lake Agassiz drainage events may affect sediment distribution and paleoflow direction within stratified sediments, particularly in low-lying areas.

The Circle Lake case study area is approximately 300 km^2 in area (*see* Figure 1). Several samples of humus and B- and C-horizon material developed within till, where available, were collected to provide a regional basis upon which to interpret the detailed sampling within anomalous catchment basins. Detailed sampling for the Circle Lake case study involved the collection of various sample media within selected catchment basins. Two catchment basins and one local hydromorphic study around 2 small lakes immediately northwest of Alwyn Lake where elevated values of PGEs were found in lake sediment samples were selected for detailed study. Within each catchment basin, stream sediment, water and organic bank samples were collected where streams are about to enter a lake or wetland area. Organic matter from wetlands and wetland water samples were also collected. Humus, B- and C-horizon soil samples were collected around several of the lakes that contained anomalous PGE values in each of the 3 areas. In addition, in-fill lake sediment sampling at 15 lakes was completed for more comprehensive coverage.

TARRISON LAKES CASE STUDY AREA

This area contains several multi-element lake sediment anomalies, thus providing a good test area to determine the best exploration follow-up methods to use. The area has been mapped as sand and gravel-rich esker and glaciofluvial delta deposits. The area covers part of a former ice marginal position with the potential input of sediment from several directions. The anomalous lakes in the northeast portion of the area were first sampled during the 1998 OGS lake sediment Garden–Obonga lakes survey. Analysis of these samples by FA–ICP–MS for PGEs during the OTH program revealed several highly anomalous palladium values. These lakes were specifically re-sampled during the 2001 OGS lake sediment Lac des Iles–Black Sturgeon Lake survey, which corroborated the earlier results. In addition to palladium, several of the lakes returned anomalous chromium, copper and nickel.

Very little bedrock outcrop occurs within the Tarrison Lakes case study area. A large body of sand and gravel, referred to as the Kaiashk Interlobate Moraine (Zoltai 1965a, 1965b), covers the bedrock surface throughout most of the case study area. Examination of its geomorphology suggests that it may be a composite feature consisting of an esker phase with sediment transport to the west-southwest followed by an end-moraine phase with sediment input from the north. It is also possible that this feature was built progressively from the west. Analysis of sedimentary structures and lithology of component rock fragments will help in understanding the genesis and various source areas contributing to the formation of this feature. To the north of the moraine are areas mapped as hummocky till and organic terrain (Mollard and Mollard 1981a, 1983). It is possible that southerly flowing ice may have extended further south prior to a westward advance south of the present-day location of the moraine.

The Tarrison Lakes case study area appears to be a preserved ice-marginal and subglacial landscape that is dominated by stratified sand and gravel deposits. Till is exposed on surface north and south of the moraine. The area has been affected by possibly 2 or more ice flow directions and the large moraine itself is probably the product of at least 2 main directions of sediment input. There are several lake sediment anomalies along the central corridor of the case study area (Dyer and Russell 2002). Some occur within the moraine and others along its margin. Studies aimed at determining the direction of meltwater movement and the composition of the various clasts making up the resultant deposits are needed to understand the formative processes of moraine development. These studies aid in the interpretation of lake sediment geochemical anomalies that occur within the moraine. Hydromorphic dispersal within the moraine sediments was also an important consideration at this site. Some of the lake sediment samples containing elevated palladium values are associated with elevated levels of nickel and copper; while others are not (Dyer and Russell 2002).

The case study area is approximately 32 km long and about 6 km wide (*see* Figure 1). Sampling was primarily concentrated in the northwestern part of the case study area around a kettle lake referred to as Badger Lake. Here, humus, B- and C-horizon sand samples were collected. Information on paleoflow directions was collected from the few scattered exposures within the Kaiashk Interlobate Moraine. Sampling of waters (springs, wetlands) adjacent to the moraine was also undertaken at selected sites within the case study area, paying particular attention to the collection of pH. Stream sediments were collected to examine the particulate component that is being transported away from the moraine. Humus and B- and C-horizon soils developed in till were collected at 2 sites along the margins of the moraine. At the detailed study site, spring water and stream sediment, water and organic bank samples were collected from the streams near their entrance into a lake or a wetland area. Organic matter from wetlands and wetland water samples were also collected where available. Eight lake sediment samples were collected, including deep and shallow sediment from Badger Lake. A complete listing of sample types and numbers for this case study area are contained in Dyer and Barnett 2005 (MRD 154).

Methods

MAPPING AND SEDIMENT SAMPLING METHODOLOGIES

The initial steps in this study involved a literature and map review to become familiar with the surficial geology of the area. The identification of major landforms and previous ice flow indicators from maps, digital elevation models and Landsat ETM imagery was done before entering the field.

Field mapping techniques included the examination of geological materials and their characteristics through the aid of existing natural and man-made exposures, soil probe cores, auger cuttings and test pits. Bedrock surfaces were examined in particular for evidence of direction(s) of ice and meltwater movement and the conditions at the base of the glacier during glacial overriding.

Observations were recorded in paper notebooks and in a digital database that was linked to georeferenced point coverage of observation site locations. At each site, information was collected on location (Universal Transverse Mercator (UTM), North American Datum 1983 (NAD83), zone 16), type of exposure, topography, position on slope, slope, and landform. Information on the materials exposed included thickness, colour, grain size, stratification, structure and upper and lower contact characteristics. In addition, soil horizon characteristics and sample locations were recorded. Materials deemed "representative" were analyzed for additional information on physical and chemical properties. The interpretation of 1:60 000 and 1:20 000 air photographs augmented field observations and aided in the production of digital maps of the surficial geology for each case study area. The 5 maps are included with this report (maps 1 to 5 in back pocket).

Till, that is "sediment that has been transported and deposited by or from glacier ice, with little or no sorting by water" (Dreimanis 1982, p.21), was the prime target sampling medium (Photo 1). In the study area, the till is generally a massive, sandy to silty-sandy diamicton with a moderate to high content of clasts. Matrix carbonate content is low. It can contain thin, discontinuous layers and lenses of sorted sediments particularly in the lee, down ice-flow, of bedrock knobs and ridges (lee-side cavity fills). At these sites, samples were collected from the diamicton layers avoiding any stratified or sorted sediment.

Soils developed in till generally consists of a thin to moderately thick humus layer (1 to 10 cm), a thin to non-existent zone of eluviation (Ae), usually less than 1 cm thick, and a B-horizon 30 to 50 cm thick (Photo 2). The B-horizon consists of a 10 cm thick dark orange brown Bf-horizon that is enriched in iron and a 20 to 40 cm thick yellow-brown to brown Bm- and/or BC-horizon. B-horizon samples tend to contain greater amounts of silt than C-horizon samples. This may be due to the breakdown of mafic and ultramafic minerals in the weathering zone. Where available, humus, "B" horizon and "C" horizon samples were collected at each site. The C-horizon till sample represents the mechanical dispersal of rock and mineral fragments by the glacier(s). B-horizon and humus samples are the response of the physical and chemical breakdown of the till to soil forming processes. In case study areas involving known sources of PGE mineralization (Lac des Iles and Tib Lake), till samples were collected to obtain information on both regional and local dispersal patterns. Where possible, samples were collected in lines orthogonal to the direction of last ice flow. In case study areas with lake sediment anomalies, some regional till samples were collected, however, sample site selection considered primarily drainage basin configuration or watershed characteristics.

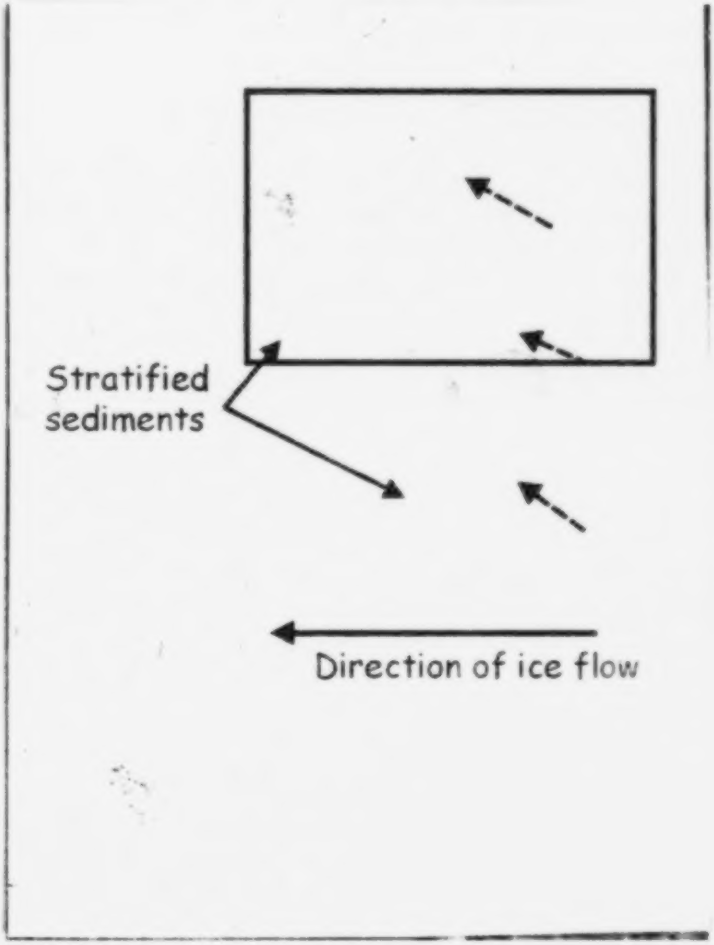


Photo 1. Till deposited in the lee of a bedrock knob north of Danby Lake in the Cheeseman Lake study area (for location, *see* Figure 32). Subglacial debris was deposited beneath an actively flowing glacier within a subglacial cavity as lodgement and deformation till (dashed arrows) and as stratified sediments (solid arrows). White box shows location of Photo 2.

Searcy (2001) had previously undertaken an investigation of PGEs in till at Lac des Iles. In areas where she had sampled, sites were evaluated as to the medium and soil horizon sampled and care was taken not to sample at the exact location. A few samples were collected near some of her sites for comparison purposes.

Sample size for geochemical analysis was approximately 1 to 2 kg. Samples were collected in breathable fabric bags, and then air-dried. Screened (–7 mm) samples weighing between 10 and 15 kg of material (stream sediment and till) were collected for heavy mineral processing. These samples were sent to Overburden Drilling Management Limited for heavy mineral concentrate processing.

Inorganic and Organic Drainage Substrate

Conventional fine-fraction geochemistry of stream sediments involved the collection of approximately 1 to 2 kg of inorganic sediment from streams bottomed by coarse clastic sediment. For such sample sites, preference was given to low-energy sites where silt-size material was available for sampling. This material was placed in breathable fabric bags and air dried in the field prior to shipment to the laboratory. Relevant sample description information included the type of material, grain size distribution (clay, silt, sand, gravel), composition (percent mafic grains) and colour. At each river or creek site where organic materials were an available substrate, well-decomposed organic materials in contact with the water were collected to help characterize hydromorphic inputs into the case study lakes. Sample sites included organic mud on the stream bottom or organic bank material from A-horizon soil in contact with stream water. A total of 127 river or creek sites were visited resulting in the collection of 91 inorganic and 71 organic sediment samples.

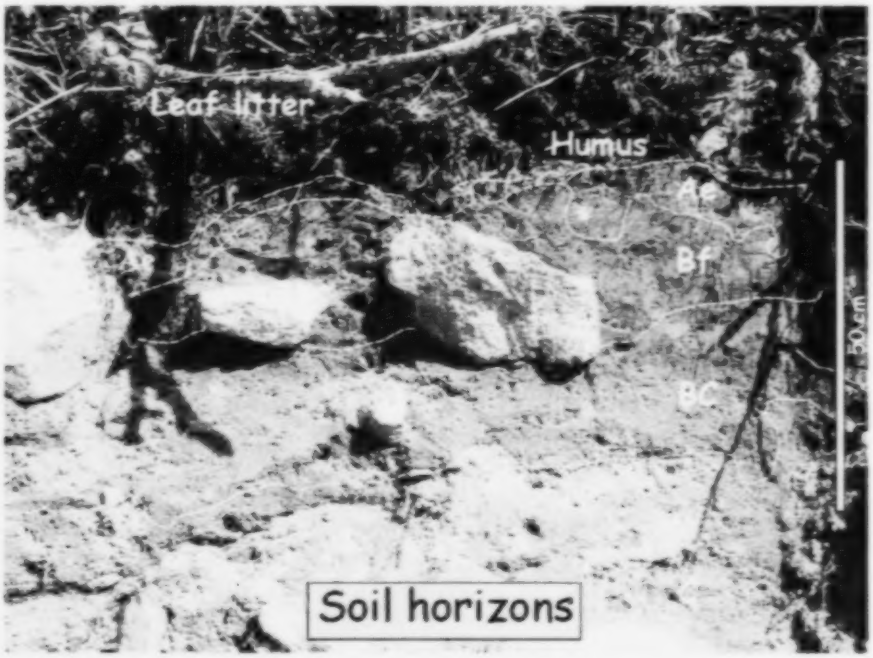


Photo 2. Common soil horizons developed in till in the LNGRI study area. Humus can be less than 1 cm to up to 15 cm thick. The mineral soil consists of a zone of eluviation (Ae), which can be absent; a zone of iron enrichment (Bf) commonly 10 cm thick; and a Bm- or BC-horizon that extends to depths of 40 to 65 cm. The Bf-horizon was targeted for B-horizon sampling and the C-horizon was usually sampled below a depth of 70 cm.

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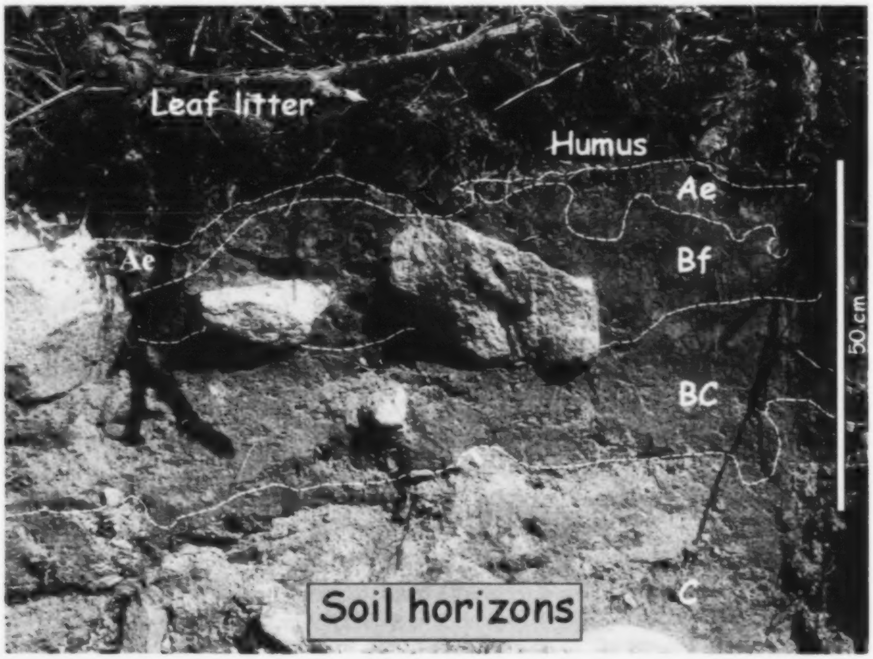

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Where present, well-decomposed peat from a depth of between 0.5 m and 1 m was obtained from bogs located at the headwaters of streams or fringing lakes. This material was placed in breathable polypropylene bags and transported in sealable plastic bags to avoid leakage and cross-contamination. Relevant sample description information included the type of sample, sample depth, texture and colour. A total of 79 peat samples were obtained from either bogs at the headwaters of streams or from bogs located on the fringe of lakes.

The history of the use of peat as an exploration media is quite long and beyond the scope of this report. A research project on this subject, including an excellent historical summary, was carried out by Thomas et al. (1987).

Lake Sediment

Standard OGS lake sediment sampling methodologies were employed for this project (Dyer and Russell 2002). Most sample sites were accessed by means of a helicopter or boat. Some lake waters were collected from the shoreline during traverses within drainage catchments. A total of 45 lakes were visited resulting in the collection of 30 lake sediments and 45 lake waters.

Water

Stream and bog waters were collected from the centre of stream channels and/or the centre of drainage pathways within bogs. Detailed sampling around lakes with anomalous sediment geochemistry involved traversing the entire shoreline area to find all possible drainage inputs into the lake (e.g., creeks, springs). Preference was given to sites exhibiting visible surface water flow. Where appropriate, water from peat bogs was sampled by first digging a sump, allowing it to fill with water, allowing suspended material to settle, and then taking the sample. Alternatively, a 0.25 mm slot piezometer pipe was pushed to a depth of approximately 1 to 1.2 m and water was extracted using a polyethylene hose and Teflon® foot valve. Stagnant water at the edge of bogs or drainage valleys was avoided. Water sampling was suspended during heavy rainfall and for at least one full day following the cessation of rainfall. Lake, stream, bog, spring and ground waters were collected in translucent 250 mL high-density screw-cap polyethylene bottles (HDPE). Only new bottles were utilized (no re-use of bottles). A total of 350 water samples were collected during this project, including 163 from streams, 50 from lakes, 54 from bogs (shallow groundwater), 48 groundwater samples (obtained by piezometers from at least 1 m depth) and 20 from natural springs. Filtration by syringe and Millipore Sterivex™[3] filters was done within minutes of sample collection, followed by acidification with ultrapure nitric acid to 0.6%. A separate aliquot for gold and PGE analysis was filtered, but not acidified.

Most waters were tested *in situ* for pH, temperature, electrical conductivity and oxidation–reduction potential (ORP) with portable handheld meters. Waters obtained by piezometer were tested within minutes of extraction. The performance of all meters was checked and recorded each night. The pH meters were calibrated daily.

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[3] Sterivex is a registered trademark of Millipore Inc.

Rock

Rocks within each case study drainage catchment were sampled. This included diabase, gabbro and any other mineralized or non-mineralized mafic rocks considered prospective for PGE mineralization. Sample sites included both outcrop and glacially transported boulders. Approximately 1 kg of representative chips were collected from different parts of each outcrop or boulder, placed in plastic bags and securely sealed prior to shipping to the laboratory. Relevant sample description information included sample type (bedrock, boulder), rock type, texture, grain size distribution (percent fine, medium, coarse), sulphide content, degree of magnetism, and colour. A total of 111 rock samples were collected during the course of this project.

Sample Locations

Precise global positioning system (GPS) co-ordinates were collected at all sample sites utilizing Trimble GeoXM™ [4] and/or GeoExplorer® [4] 3 receivers. All GPS co-ordinates were collected and saved in North American Datum 1983 (NAD 83), Zone 16. Daily downloading to a notebook computer and periodic backup of data, by recording to CD-ROM, ensured data safety and integrity. Sample site locations were also plotted on airphotos and/or 1:50 000 scale topographic maps in the field at the time of collection.

SAMPLE PREPARATION AND ANALYSIS

Sample Preparation

LAKE SEDIMENT

Dried lake sediment samples were submitted to the laboratory and prepared as follows:

1. Samples disaggregated using a non-contaminating mild steel ring and puck pulverizer for approximately 10 seconds.
2. The entire sample was sieved at 80 mesh (180 µm), using nylon sieves. All sieves were thoroughly cleaned between samples with a jet of compressed air.
3. The –80 mesh fraction was weighed and returned to the OGS for insertion of quality control standards. The +80 mesh material was retained and stored.

HUMUS, PEAT, ORGANIC STREAM SEDIMENT

Dried humus, peat and organic stream sediment samples were submitted to the laboratory and prepared as follows:

1. Samples were gently disaggregated using a morter and pestle.
2. The entire sample was sieved at 50 mesh (300 µm), using nylon sieves. All sieves were thoroughly cleaned between samples with a jet of compressed air.
3. The –50 mesh fraction was weighed and returned to the OGS for insertion of quality control standards. The +50 mesh material was retained and stored.

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[4] GeoXM and GeoExplorer are registered trademarks of Trimble GPS Ltd.

INORGANIC STREAM SEDIMENTS AND GLACIOFLUVIAL SANDS

Dried inorganic stream sediments and sands were sent to the laboratory and prepared as follows:

1. Samples were gently disaggregated, if necessary, followed by sieving at 80 mesh (180 µm), using nylon sieves. All sieves were thoroughly cleaned between samples with a jet of compressed air.
2. The –80 mesh fraction was weighed and returned to the OGS for insertion of quality control standards. The +80 mesh material was retained and stored.

"B"-HORIZON SOIL AND "C"-HORIZON TILL

Dried soils and tills were submitted to the laboratory and prepared as follows:

1. Samples were gently disaggregated, if necessary, followed by sieving at 250 mesh (63 µm), using nylon sieves. All sieves were thoroughly cleaned between samples with a jet of compressed air.
2. The –250 mesh fraction was weighed and returned to the OGS for insertion of quality control standards. The +250 mesh material was retained and stored.

ROCKS

Rocks were prepared as follows:

1. Rock samples were crushed in a primary jaw crusher that was first thoroughly cleaned using silica sand and brushes. A representative riffle split subsample of the crushed material was thoroughly pulverized using a mild steel ring and puck pulverizer.
2. The resulting pulps were returned to the OGS for insertion of quality control standards. The oversize material was retained and stored.

Sample Analysis

Laboratory analysis of inorganic and organic media was carried out as follows:

LAKE SEDIMENT

1. Aqua-regia digestion of 0.5 g followed by an ICP–MS–OES scan.
2. Fire assay using 10 g of sample material with an ICP–MS finish for the analysis of Pd, Pt and Au.
3. Instrumental neutron activation analysis (INAA) of a 10 g pressed briquette.
4. Loss-on-ignition (LOI) @ 500°C on 0.5 grams of material.

HUMUS, PEAT, ORGANIC STREAM SEDIMENT

1. A 50 g subsample of dried material was reduced to ash followed by aqua-regia digestion of the ash and analysis by ICP–MS–OES.
2. Fire assay using 10 g of sample material with an ICP–MS finish for the analysis of Pd, Pt and Au.
3. Instrumental neutron activation analysis (INAA) of a 10 g pressed briquette.
4. Loss-on-ignition (LOI) @ 500°C on 0.5 g of material.
5. Humus and peat samples were also analyzed by Enzyme Leach$^{\text{SM}}$[5]–ICP–MS.

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[5] Enzyme Leach is an unregistered Service Mark of Activation Laboratories Ltd.

INORGANIC STREAM SEDIMENTS AND GLACIAL DEPOSITS (GLACIOFLUVIAL SAND, "B"-HORIZON SOIL, "C"-HORIZON SOIL)

1. Aqua-regia digestion of 0.5 g followed by an ICP–MS–OES scan.
2. Fire assay using 30 g of sample material with ICP–MS finish for the analysis of Pd, Pt and Au.
3. Sands and "B" horizon soils underwent instrumental neutron activation analysis (INAA) of 30 g (encapsulated in vials).
4. Loss-on-ignition (LOI) @ 500°C on 0.5 g of material.

ROCKS

1. Multi-acid (hydrochloric, nitric, hydrofluoric and perchloric) digestion of 0.25 g followed by an ICP–MS–OES scan.
2. Fire assay using 30 g of sample material with an ICP–MS finish for the analysis of Pd, Pt and Au.
3. Whole rock analysis by XRF.

WATER

All water samples were filtered at 0.45 µm and preserved, as appropriate, as described in the waters method section above. No further preparation at the laboratory was required. The following analytical procedures were carried out:

1. Preserved (acidified) aliquot underwent direct aspiration ICP–MS.
2. Non-preserved (but filtered) aliquot underwent a laboratory proprietary technique to re-dissolve Au and PGEs adhering to the walls of the plastic sample bottles followed by direct aspiration high resolution (HR)-ICP–MS for Au and PGEs.

QUALITY CONTROL RESULTS

General Comments

Table 1 outlines the types of certified reference materials and OGS internal standards used in this project. After sample preparation at the laboratory, all pulps were returned to the OGS for insertion of quality control (QC) samples. Greater than 1 in every 10 samples submitted to the laboratory was a certified or OGS internal standard. Duplicate samples (field duplicates and pulp splits) were also submitted at a rate of approximately 1 in 10. Analytical pulp duplicates were prepared by halving the dried sample pulps and inserting them into the sample sequence. CANMET certified reference standards (e.g., Lynch 1990) and OGS internal standards were inserted as dried pulps between the sample preparation and analysis stages.

Appendix 1 contains geochemistry summary tables grouped by type of media sampled. As a minimum, each table shows the elements Co, Cr, Cu, Ni, Pd, Pt and Au, including some basic statistics of the geochemical data sets, and quality control data such as estimates of precision and coefficients of variation for the reference materials. A complete listing of all data used to prepare these tables are contained in the Miscellaneous Release—Data (MRD 154) published separately from this report.

Analytical precision for each of the elements in the summary tables in Appendix 1 were determined by plotting duplicate data on an X–Y chart and determining the variation of 95% of the data from a

Table 1. Certified reference materials and internal (OGS) standards.

Media	Certified Standards	Internal (OGS) Standards
Lake Sediments	LKSD-4	OGS-1
Water	SLRS-4	Ultrapure Water
Organic Stream Sediments	LKSD-1	OGS-1
Humus	LKSD-4	OGS-1
Inorganic Stream Sediments	LKSD-2	OGS-1
Sands		OGS-1
B-Horizon	TILL-1	MCM-1, OGS-1
C-Horizon	TILL-1	MCM-1, OGS-1
Rock	TDB-1	LDI-1, OGS-1
Peat	LKSD-4	OGS-1

1:1 ratio. Accuracy was determined by plotting the sequential values returned for certified reference standards inserted in the batch against a vertical scale of concentration and comparing this with the certified or accepted values for the standards.

In general, the determinations of all base metals (e.g., Cu, Ni, Co) in the QC samples displayed excellent precision and accuracy; the majority of the precision estimates fall within a range that, in OGS experience, are typical and expected for the methods employed. The only exceptions were found in the accuracy of Cr determinations by aqua-regia–ICP for all media and the reproducibility of metals determined by ashed ICP on peat and organic stream sediment samples. Chromium levels by ICP were low in all the certified reference materials (CRMs) and probably resulted in a low bias in the unknowns. The aqua-regia digestion employed is a strong but not total digestion, in which Cr is commonly incompletely attacked. The results for Cr by INAA show much better accuracy, however, the sensitivity and reproducibility of this method is poorer (see QC tables in Appendix 1). The reproducibility of the metals of interest (in particular Cu) in the ashed ICP–MS duplicate pairs was poor compared to duplicates in the other sample streams (e.g., inorganic stream sediments, lake sediments) that underwent traditional direct aqua-regia digestion ICP–MS. Further details are presented in the sections below.

Overall, the precision of FA–ICP–MS elements (Au, Pt and Pd) was excellent and is the preferred methodology for Au and PGE determinations. The precision for the precious metals by the ashed ICP–MS technique were significantly worse than by FA–ICP–MS. In general, there was poor corroboration for Au between INAA, FA–ICP–MS and ashed ICP–MS. In OGS experience, this is typical and, to a large degree, reflects the classic nugget ("particle sparsity") effect rather than an analytical issue at the laboratories. For meaningful interpretation of the precious metals results, the precision estimates shown in Appendix 1 should be taken into account and caution exercised where appropriate.

Overall, the quality of the instrumental neutron activation analysis (INAA) was excellent. The estimated precision, from the analysis of duplicate pairs, for Au ranged from 3 to 5 ppb, which is excellent for the INAA method.

Detailed comments regarding the quality of the geochemical analysis of each type of media are contained in the sections below.

Humus

Humus samples underwent the ashed ICP–MS technique for determination of base and precious metals. Precision of the base metals of interest was relatively poor compared to the more conventional and widely used direct aqua-regia digestion-ICP–MS technique. In particular, the estimated precision of Cu (±20 ppm) is double the value estimated for the B- and C-horizon samples. The average metal results from the reference materials indicate good accuracy, with the exception if Cu and Cr. Chromium levels by ICP determined in the reference materials were low (e.g., average of 17 ppm in LKSD-4, certified level is 33 ppm) indicating the likelihood of a low bias in the unknowns. Conversely, Cu levels were, on average, approximately 150 ppm high in OGS-1; this suggests a possibly high bias in the unknowns. The precious metals (Pd, Pt and Au) determined in the reference standards were also erratic by the ashed ICP–MS method. There is almost no corroboration between the levels of precious metals determined by the ashed ICP–MS and the FA–ICP–MS methods; QC results indicate the latter method returned good precision for Au, Pd and Pt, although levels of Pd and Pt may be biased low. Therefore, the precious metals determined by FA–ICP–MS should be considered more reliable and take precedence over the ashed ICP–MS results. There is good correlation between Au determined by FA–ICP–MS and by INAA, therefore, either can be used with confidence.

Gold determined by Enzyme Leach^{SM} in the reference standards was erratic; therefore, the unknowns data should be considered suspect. The performance of Ni and Cu by Enzyme Leach^{SM} in the standards was good. All Pd and Pt data for the CRMs were below detection limits.

B-Horizon Soil and C-Horizon Till

The QC results for Co, Cu, Ni and Cr indicate good to excellent reproducibility (precision) within both the B- and C-horizon sample streams. In terms of accuracy, comparison of the Cu results in the CRMs with the accepted values indicates a low bias that may be mirrored in the B-horizon unknowns. The results of the FA–ICP–MS analysis for Au and PGEs indicate overall good precision. Levels of Pt determined in the B- and C-horizon streams may be biased low. In addition, Pd determined in the C-horizon sample stream standard (OGS-1) are significantly lower than accepted values, suggesting a low bias within the C-horizon unknowns.

Gold determinations in the certified reference materials in both the B- and C-horizon sample streams are noisy, but there appears to be no adverse effect on the unknowns in terms of sympathetic ramping or spikes.

Sands (Glaciofluvial and Modern Alluvium)

Overall, the quality of the results for the analysis of sands was very good; no significant issues were identified. Levels of Au, Pd and Pt by fire-assay determined in internal standard OGS-1 were approximately one-half of the accepted values, therefore, the levels returned for the unknowns may be low.

Peat

The only issues identified within the QC results for peat samples are for the precious metals by ashed ICP–MS and Au by Enzyme Leach^{SM}. Significant noise in the results of Pt, Pd and Au by ashed ICP–MS detected in the reference materials indicates that only values above 3 to 4 ppb may be significant. Similarly, erratic levels of Au determined by Enzyme Leach^{SM} in the reference standards indicate that some of the Au levels above 0.02 ppb may be artefacts related to the analytical method.

As noted in the general comments section above, precision estimates for base metals (Co, Cu, Cr, Ni) determined by ashed ICP–MS are worse than typically achieved through the more commonly utilized method of direct aqua-regia-ICP–MS. Therefore, the precision estimates contained in the table in Appendix 1 should be consulted when interpreting the base metal results. The levels of metals determined in the certified reference material (CRM) LKSD-4 are low for Cu and Cr, as a result, levels of these elements in the unknowns may also be biased low.

Inorganic Stream Sediment

The QC results for Co, Cu, Ni and Cr by ICP indicate good to excellent reproducibility (precision). However, comparison of the results of these elements with the accepted values of the CRMs, in particular for Cr, indicate poor accuracy (with a low bias). The results of the FA–ICP–MS analysis for Au and PGEs indicate good precision. Accuracy for these precious metals is also good, although levels of Pd are also biased low.

Gold determined by INAA shows poor reproducibility and accuracy in the CRM LKSD-2 and the internal reference material OGS-1. This suggests that the precision of the analysis is worse than the ±5 ppb calculated from the duplicate pairs and that only levels >10 ppb in the unknowns are significant. The INAA analysis of some of the inorganic stream sediment samples collected in 2004 (13 of 18 collected), contrary to OGS instructions and specifications, was carried out on very small sample sizes ranging from 0.7 to 2.0 g. In OGS experience, the main effect of such a small sample size can be unreliable Au determinations due to exacerbation of the nugget effect. This is evident in the results of 2 of the low sample weight INAA analyses: 1) a sample of OGS-1 (04-RDD-5004, sample weight 0.7 g) returned a level of 22 ppb Au (accepted value is 11.8 ppb); and 2) a sample of LKSD-2 (04-RDD-5011, sample weight of 1.2 g) returned a value of 13.5 ppb Au (certified value is 3 ppb). Therefore, caution should be used in the interpretation of low sample weight INAA results. Within the batch of low INAA weight stream sediment samples, the Au results from sites Tib-SS-10, Tib SS-13 and Tar-SS-8 should be interpreted with caution.

Organic Stream Sediments

Organic stream sediment samples underwent the ashed ICP–MS technique for determination of base metals. As with the peat samples, precision of the metals of interest was relatively poor compared to the more conventional and widely used direct aqua-regia digestion-ICP–MS technique. In particular, Cu reproducibility was very poor (±100 ppm). However, the average metal results from the reference materials indicate good accuracy, with the exception of Cr. Chromium levels determined in the reference materials were very low (e.g., average of 3.8 ppm in LKSD-1, certified level is 31 ppm) and erratic, indicating that only levels above 20 ppm are meaningful. Chromium determined by INAA in the QC samples demonstrated better accuracy and reproducibility.

The precious metals determined in the reference standards were also erratic by the ashed ICP–MS method. In particular, Pt levels are likely only meaningful at levels above 8 ppb. There is very little corroboration between the levels of precious metals determined by the ashed ICP–MS and the FA–ICP–MS methods; the latter method returned very good precision and accuracy for Au, Pd and Pt.

The estimate of precision for Au by INAA of ±6 ppb is also reflected in the performance of the CRMs and suggests that only levels above 6 to 7 ppb would be significant.

Lake Sediments

The only QC issue identified in the laboratory analysis of the lake sediment samples was for the FA–ICP–MS elements (Au and PGEs). The results for OGS-1 inserted within the lake sediment sequence samples show the levels of Pd, Pt and Au drop significantly halfway through the sample sequence. The consequence is that some samples, mainly the Circle Lake case study samples, may have had lower levels of precious metals reported than actually exist.

Rocks

The results from duplicate samples and reference materials indicate excellent precision for the precious and base metals. Accuracy was also very good, with the sole exception of Cr, which was reported to be consistently low in certified reference material TDB-1.

Waters

The estimated precision for elements determined in waters is based on the analytical results of field duplicates and sample splits. Overall, reproducibility (precision) was excellent; estimates of precision are contained in Appendix 1. The results of the blanks and CRM (SLRS-4) indicate a possible problem with some of the 2004 year Cr results, specifically for sites RAC-BOG-3 and RAC-BOG-5 to 9. In general, the precision estimates based solely on analytical splits achieved the best (lowest) numbers, as would be expected. The results for certified reference material (CRM) SLRS-4 indicate that a high level of accuracy for the metals was achieved.

The direct analysis of Au and PGEs by high resolution ICP–MS to the parts per trillion (ppt) level represents a significant step forward in hydrogeochemical exploration. The precision estimates, again based on 28 field duplicates, are exceptional. In particular, the Pt results are very interesting, with a median level above detection limit and a range of data broader than that of Pd (Pd is more soluble than Pt). The estimated precision of one-tenth (0.1) of a ppt is astounding. Spectral interferences on Pd required some significant corrections, therefore, it is possible that some loss or truncation of the true Pd geochemical signal has occurred. This may account for the tighter range of Pd data compared to the Pt data. Noise (spikes) in the blanks (pure and distilled water) indicate that only Au data above 1 to 2 ppt should be considered significant and the Ru data are unreliable, likely the product of analytical variation. The performance of Au in SLRS-4 suggests that precision is closer to ±2 ppt rather than the estimate based on duplicate pairs of ±0.4 ppt.

Sampled Media Results

TILL: GLACIAL DISPERSAL

Till is a useful sample media for mineral exploration and for mapping bedrock geochemistry in covered areas between bedrock exposures (outcrops and trenches). With proper sampling density, dispersal trains within till can be defined, such as in the Lac des Iles case study area.

The till in the area is for the most part thin (commonly <4 m) and deposited directly from the base of the glacier and, hence, reflects the composition of bedrock and other materials immediately up-ice flow direction from the sample site. Till or flowtills within the small ridges (washboard or DeGeer moraines) common in the Circle Lake area, appear to be composed of glacial debris that was transported and deposited at the base of the glacier making this material suitable for sampling in mineral exploration surveys using till.

Dispersal trains or plumes can be observed in both heavy mineral (e.g., chromites and chrome andradite garnet) and till (C-horizon) geochemistry results (e.g., Ni, Cr , Cu and Co) at Lac des Iles. Dispersal train widths commonly correspond to the width of the subcrop of the mineral of interest. At Lac des Iles, several composite trains of chrome andradite garnet measure about 7 to 8 km in length and vary between 400 and 600 m in width. Individual trains are more likely 1.5 to 4 km in length. Chromite dispersal trains are not as well defined as the chrome andradite garnet trains, however, they are in the order of 500 m to 2 km in length depending on the initial concentration of chromites: that is, the higher number of grains, the longer the dispersal train. Regional geochemical dispersal trains of elements such as Mg, Cr, Ni and Co associated with the Mine Block intrusion can be detected for about 4 km beyond its western (down-ice flow) margin. Entire regional dispersal trains range from 5 to 7 km in length and about 1 to 2 km in width.

Dispersal trains of Pt, Pd and Au are not well defined and tend to be very short, less than 1 km in length, due to the initial low concentrations of these elements in C-horizon till samples from the Lac des Iles area. Coker and others (1991) describe glacial dispersal trains of PGE minerals in the silt to clay fraction of till that are 100 to 200 m in length in the Ferguson Lake area, NWT and about 1 km in length for Pt and Au in geochemical analysis of heavy mineral concentrates at Rottenstone Lake, Saskatchewan.

Dispersal trains of about 6 to 7 km in length and 1 to 2 km in width for Ni, Cr, Mg and Co are oriented parallel to the latest ice flow direction about 240 to 245° in the Lac des Iles area. By using an automated contouring method (kriging) that accounts for the anisotropy of glacially dispersed debris, 3 distinct dispersal trains for Cr and Mg, 3 to 5 km in length and 300 to 500 m in width were delineated. For Ni, 5 smaller trains are indicated, 3 of which correspond to the trains of Cr and Mg. The largest of the trains of Ni, Cr and Mg correspond to the major train of chrome andradite garnet distribution. A Ni dispersal train (silt to clay fraction of till) has been defined by Shilts (1973) from ultrabasic rocks in the Thetford Mines area of Quebec that has a length of over 60 km. However, high values drop off rapidly a little more than 1.6 km away from the source (Shilts 1973).

The patterns of the associated trace elements, such as Ni, Cr and Mg, indicate that although the rocks of the Mine Block intrusion and surrounding area are very similar in appearance, there are significant variations in trace element chemistry. In general, the associated trace elements form larger dispersal trains than PGEs due to their greater initial abundance making them larger targets for mineral exploration surveys using C-horizon till samples.

One problem for a till sampling program is obtaining an adequate spatial distribution of samples. In many areas such as Cheeseman and Circle Lake case study areas, till is commonly very thin and soil forming processes have affected the entire thickness of the till. Essentially, unaltered C-horizon samples are difficult to obtain. Elsewhere, the till can be buried beneath thick glaciofluvial or glaciolacustrine stratified sediments as in the case at Tarrison Lakes (thick glaciofluvial sediments) and the Tib (thick glaciolacustrine sediments) case study areas. In these areas, till may or may not be present beneath the stratified sediments.

In summary, conditions for using C-horizon till for mineral exploration in the Lake Nipigon Region are good:

1. The till is subglacially deposited thereby reflecting bedrock conditions immediately up-ice flow;
2. the till appears to represent the last ice movement in the area; and
3. till is laterally extensive and in most cases thick enough to obtain C-horizon samples (exceptions noted above).

Well-defined geochemical dispersal trains were observed in sample results of C-horizon till and heavy mineral concentrates of the till, particularly at Lac des Iles, where sampling density was sufficient. Dispersal trains for PGEs were found to be commonly short, however, the trains of associated elements such as Ni and Cu are much larger and provide a much bigger target area for mineral exploration. Regional sampling provides information on regional dispersal and will help in defining areas of interest for follow-up sampling. C-horizon till is the first derivative of the bedrock. If the direction of last movement is known, then it can be used to trace elements, mineral and/or rock fragments back to their source.

SOIL AND SOIL-FORMING PROCESSES IN GLACIAL SEDIMENTS

Following deglaciation, the materials making up the land surface were exposed to weathering and soil forming processes. The parent material (C-horizon) of the soil began to alter physically and chemically in response to these processes and other soil horizons formed. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter) was also sampled during this project.

In all of the case study areas that have soils developed entirely in till, there is generally a decline in concentrations of Pt, Pd, Ni, Cu, and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7). Soils in the Lac des Iles area, that have been affected by anthropogenic processes, have a Type 2 profile (*see* Figure 7) and are discussed in greater detail below.

Platinum, Pd, Ni, Cu, and Cr appear to be moving both within and out of the soil system downslope into surface and shallow groundwater. It is suggested that these elements, to varying degrees, are moving in solution. Similar findings have been reported previously in several other papers (Wood 2002). The elements Pt, Ni, Cu, Cr and Co were found to be enriched in seepage samples around the Tulameen ultramafic complex in southern British Columbia (Cook and Fletcher 1993, 1994; Fletcher et al. 1995). Fletcher and others suggested that Pt was transported "into the seep by inflowing waters and then adsorpted by organic matter" (Fletcher et al. 1995, p.44) indicating that Pt and the other elements were being removed in solution from the soil and rocks at this site. Fuchs and Rose (1974) investigated the behaviour of Pt and Pd in the weathering cycle at the Stillwater Complex in Montana. They suggested that Pd was being removed from the upper soil horizons and transported as chloride complexes in water. Coker et al. (1991) also suggested that Pd is moving in solution at Rottenstone Lake, Saskatchewan. Wood and Vlassopoulos (1990), who looked at the dispersion of Pt, Pd and Au in surficial media around 2 PGE-Cu-Ni prospects in the Lac Sheen and Lac Long–Lac Montauban area, Quebec, suggested that Pd moved in solution, however, Pt and Au were moved primarily as particles. Cameron and Hattori arrived at similar conclusions in the Lac des Iles area (Cameron and Hattori 2003, Hattori and Cameron 2004). Bajc and Hall (2000) in the Sudbury area suggested that Pt and Pd in soils are migrating according to local Eh–pH conditions.

Although the soil profile geochemistry of Pt is similar to that of Pd, in general, the mobility or degree of decrease in concentration up the soil profile is less than that of Pd. Fuchs and Rose (1974, p.333) also suggested that there is "good evidence that palladium is more readily leached than platinum." Copper behaves similarly to Pd and is very mobile in soils in the Lake Nipigon region. There is not as much removal of Ni as occurs with Cu in the B-horizon, that is, the geochemical gradient or mobility is not as great for Ni as Cu.

Fuchs and Rose (1974) suggested that, at the Stillwater Complex in Montana, Pt is enriched in the B-horizon possibly being trapped "in oxides". At a few sites in the Lake Nipigon region, Pt concentrations and the concentrations of several of the more mobile elements were greater in the B-horizon than C-horizon. These sites, however, are commonly located at the base of steep bedrock-controlled slopes where downslope movement of these elements in surface and shallow groundwater may have added to their concentrations in the B-horizon.

Gold and Zn commonly illustrate the Type 2 geochemical profile type in soil profiles developed in till from all case study areas (*see* Figure 7). A Type 2 geochemical profile has a general decline in element concentrations up through the mineral soil horizons, however, it has maxima in the humus layer (Klassen 2003). For these elements, biological processes are the preferred mechanism of enrichment in the humus in contrast to an anthropogenic input (airborne contamination). Fletcher and others (1995) also suggested that Zn concentrations were elevated in humus (leaf litter and spruce trees) around the Tulameen ultramafic complex in southern British Columbia.

The majority of sites in the Lac des Iles case study area, however, have the Type 2, "accumulation (surface)", profile, that is, a net downward increase with humus maxima (Klassen 2003) for Pd, Pt, Cu and to a lesser extent Ni (*see* Figure 7). There are major disconnects between the mineral soil layers and the humus at Lac des Iles. Concentrations of these elements can be 10 to 100 times larger in humus samples than the corresponding B- and C-horizon samples. Differences in concentrations between humus and C-horizon samples collected at the same sites generally decrease eastwardly from the mine workings, waste rock and tailings areas (e.g., *see* Figure 12 in "Case Study Area Results"). This relation is believed to be the result of airborne contamination of humus samples by dust from disturbed areas (anthropogenic input). Airborne contamination of the humus at this case study site has adversely affected the ability to determine the effectiveness of humus sampling for mineral exploration. The airborne contamination likely influences surface and groundwater and organic bog samples as well, particularly for elements of initial low concentrations such as Pt and Pd.

Geochemical profile Type 3, "accumulation (subsurface - organic)", and profile Type 4, "secondary accumulation (subsurface - inorganic)" are not present in the study areas.

The Type 5 profile, "geogenic"—different materials, stratigraphy, within the soil profile or a change in parent material through the soil profile (Klassen 2003; see Figure 7)—occurs at the Tib Lake, Circle Lake and Cheeseman Lake case study areas. There is a chemical disjunct between the surface postglacial sand and till parts of the mineral soil layers at the Tib Lake case study area and between the thin cover of till over bedrock or residual soil at the Circle Lake and Cheeseman Lake case study areas. Sites at Tib Lake were not sampled for B-horizon and humus because interpretation and backtracking anomalies to their source is very difficult. At Circle Lake and Cheeseman Lake, care was taken to identify and record the original parent material so that these differences could be taken into account during geochemical data interpretation.

In areas with sediments containing even low amounts of carbonate (>5% of the matrix), such as at the Tarrison Lakes case study area, the mobility of some elements, in particular Ni, is decreased. Variations observed in Ni, Zn, Co and Cr content between the B- and C-horizons are minimal, indicating that very little of these elements are entering into solution to be distributed by hydromorphic processes. Nickel, Co and Cr concentrations commonly decrease in humus samples in areas of elevated carbonate content and pH.

Most of the elements of interest occur in greater abundance in C-horizon samples than in B-horizon samples. This might lead one to the conclusion that sampling the C-horizon might be the best method for mineral exploration of PGEs. However, for several trace elements, the results of B-horizon samples are useful. For Ni, Mg and Cr, B-horizon sample results target only the heads of dispersal trains defined by C-horizon samples. The B-horizon targets are much smaller, however, there is some evidence of downslope movement of elements and blurring of the target area (hydromorphic dispersal).

Humus samples in all the case study areas commonly contain lower values of Pt, Pd, Cu, Ni and Cr than the concentrations of these elements in the corresponding mineral horizons of the soil. This trend appears to be the reverse of results obtained for these elements in the Sudbury area (Bajc and Hall 2000; Tardif 2000). Gold and Zn, however, are often enriched in humus. The humus samples collected at Lac des Iles appear to be contaminated by airborne dust derived from mining operations. This is best illustrated with Pd and Pt, elements that have initially low natural concentrations (e.g., *see* Figure 12 in "Case Study Area Results"). Whereas glacial dispersal (C-horizon results) has created geochemical gradients toward the southwest, the geochemical gradient in the humus samples is generally eastward.

In summary, the behaviour of Ni in the soil environment is similar to that of Pt and can be used as a proxy under most conditions for geochemical exploration. In areas of elevated pH, Ni does not appear to be as mobile as Pt and, therefore, their pathways through the soil environment diverge. The behaviour of Cu in the soil environment is similar to that of Pd with respect to relative mobility. Geologically, Pt and Ni and Pd and Cu are often associated.

SOIL AND SOIL-FORMING PROCESSES IN BEDROCK

Within the Lake Nipigon region, there are large areas of bedrock-controlled plateaux underlain primarily by Nipigon diabase sills. The surfaces of the plateaux contain numerous depressions of various sizes that are commonly filled with lakes. The lakes are rimmed by a series of bedrock-controlled steps or escarpments, some of which exceed 30 m in height. The overall irregular surface of the diabase sills, particularly in the Cheeseman Lake and Tarrison Lakes areas, is similar to that of the Channelled Scablands of eastern Washington State (Baker et al. 1987). The only difference is that, here, the surface has been streamlined and till overlies the sculpted bedrock surface. Like the Channelled Scablands, a large discharge (floods) of meltwater is proposed as the mechanism of formation, however, in the Nipigon region, meltwater flowing beneath the glacier is proposed.

The surfaces of the plateaux are also cut by curvilinear to linear valleys likely controlled by fracture systems developed in the sills. Areas of highly weathered sill rocks, altered to depths exceeding 5 m, tend to occur along valley edges, and rounded core-stones floor the valleys. These relations suggest that deeper weathering has occurred along fractures in the sills and that subsequent removal of the less cohesive weathered rock (residual soil) has produced the valleys.

In the Cheeseman Lake and Circle Lake case study areas and areas in the Lake Nipigon region that are underlain by Nipigon sills, till commonly forms only a veneer over the bedrock surface, particularly on top of bedrock-controlled plateaux. On the plateau tops, B-horizon soils are commonly developed in either thin till or bedrock (residual soil), C-horizon soils are not developed in till and the Type 5, "geogenic", soil geochemical soil profile type of Klassen (2003) occurs. At several sites, the till cover over bedrock was too thin to collect B- and/or C-horizon till samples. At these sites, the weathered bedrock or residual soil was noted and sampled. B- and C-horizon samples of both till and residual soil were collected during this study, however, consideration of this was taken during the interpretation of geochemical results for B- and C-horizon samples.

The development and preservation of residual soils is not uncommon in areas underlain by mafic to ultramafic rocks and, in particular, of the Nipigon diabase sills (e.g., Cheeseman Lake and Circle Lake case study areas). Areas of deep (>3 m) residual soils occur in the down ice-flow protected side of rock knobs and ridges indicating that the weathering processes may have operated prior to the last glacial event. However, large rotted boulders in till and glacial gravel and sand deposits, and weathered bedrock beneath till in unprotected areas, such as plateau surfaces, indicate that the disintegration and weathering of the bedrock are also postglacial and ongoing processes.

The Nipigon diabase sills are composed of medium- to coarse-crystalline feldspar and pyroxene that should properly be classified as gabbro (Hart and Whaley 2004). Gabbro is approximately 10 times greater than diabase with respect to water absorption (Kazi and Al-Mansour 1980) and "rocks with high absorption values will be more susceptible to both physical and chemical weathering" (Gerard 1988, p.90). The coarse-textured nature of the sills, the extensive joints and fractures combined with the mineralogy and water absorption characteristics support both physical and chemical weathering processes. Deep weathering occurs downward from the surface and along fractures and joints producing a granular residual soil with the development of corestones near the base of the weathering front. Grain size analysis of 4 samples of residual soil (C-horizon) averages approximately 92% sand, and 8% silt-size particles. The granular nature of the residual soil developed in the Nipigon sills promotes water movement through the soil (relatively high permeability), greater mineral–water interactions and deeper soil development (enhanced soil-forming processes) within the bedrock.

The results of deeper soil development in these rocks are displayed by the occurrence of loose, granular gabbroic sand (residual soil) along fractures and joints adjacent to competent gabbro at depth and by valley bottoms littered with rounded corestones. Along these valleys, the granular residual soil has been removed by stream erosion leaving the larger corestones behind particularly in the Cheeseman Lake case study area. Surface water and groundwater has transported minerals and rock fragments downstream to be deposited as stream or lake sediment. Elements, such as Pd and Cu and, to a lesser extent, Pt and Ni, likely move in solution as well and potentially affect levels of these elements in both stream and lake water.

Many sites, particularly on plateau surfaces in the Cheeseman Lake and Circle Lake case study areas, have the Type 5, "geogenic", profile, that is, different materials, stratigraphy, within the soil profile or a change in parent material through the soil profile (Klassen 2003; *see* Figure 7). At these sites, there is also a chemical disjunct between the thin layer of till at the surface and the weathered bedrock or residual soil making up the mineral soil layers at depth.

In soils developed entirely in bedrock, there is generally a decline in concentrations of Pt, Pd, Ni, Cu, and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7). In the composite thin till over bedrock settings, a Type 5, "geogenic", geochemical soil profile (Klassen 2003; *see* Figure 7) occurs. However, as a result of the large difference between the initial trace element concentrations in the bedrock and that in the till, there is a decline in the concentration of Pt, Pd, Ni, Cu, and Cr up through the soil profile (Type 1: Klassen 2003). There are also major decreases in Pt, Pd and Au concentrations in humus samples as compared to B-horizon samples developed in residual soil.

In summary, the cover of till is thin and discontinuous. The lengths of water flow-paths (surface and groundwater) in contact with bedrock and particularly residual soil in this setting is much greater than that in till. As a result, the contribution of the till to the anomalous trace element concentrations in lake sediment is probably minimal. Waters flowing in contact with the bedrock surface and through fractures and joints filled with loose granular residual soil most likely explain the lake sediment anomalies. Trace element values measured in residual soil samples could adequately explain the values obtained in the lake sediment geochemical survey.

SANDS

Samples of sand were collected only at the Tarrison Lakes and Circle Lake case study areas. In the Tarrison Lakes area, they were not collected with the intention of use as an exploration medium, but rather to determine their chemical characteristics as a possible source of metals to the anomalous lake sediment geochemistry in Badger Lake. At the Circle Lake study area, the sand samples were collected from the base of springs centred on deeply incised valleys along the Thread Lake drainage system. In essence, these are modern alluvium samples and the material likely originated from residual soil (weathered diabase) from the valleys. However, the levels of major elements (e.g., Al, Ca, K and Mg), REEs and REE ratios in the sands are significantly different from the diabase samples collected along the Thread Lake drainage valley. Conversely, the levels of Au, Cu, Ni, Pd and Pd determined in the sands are similar to that determined in the diabase samples. In any case, the use of sands as a surficial media for exploration is site specific and a question of scale. In an area such as Tarrison Lakes, the sand is clearly glaciofluvial, potentially long travelled and very difficult to trace to source. At the Circle Lake study area, the sands can be related to a more local source, related to postglacial weathering and the development of drainage valleys along bedrock valleys in the diabase.

HYDROGEOCHEMISTRY

With the exception of the Tarrison Lakes study area, sampled water pH levels were generally near neutral (pH = 7.0) to slightly acidic. The pH of groundwaters was typically more acidic than surface waters. This indicates surface and subsurface pH conditions conducive for hydromorphic transport of metals.

Relatively high pH levels (average = 7.6) characterize the waters sampled in the Tarrison Lakes study area. As a consequence, most metal levels in the Tarrison Lakes study area waters are very low. The exceptions are Mo and U, which, on average, are higher in Tarrison Lakes area waters than any of the other study areas, in part, due to their mobility in alkaline conditions.

Groundwater

BOG WATER

A total of 76 bog waters, most from dug sumps, were collected during this project. The majority of these samples were obtained from the Cheeseman Lake and Lac des Iles study areas. Samples were obtained near areas of known mineralization (Lac des Iles and Tib Lake study areas), within lake sediment anomalous drainage catchments (Cheeseman Lake and Circle Lake study areas) and from background areas well away from known bedrock mineralization or lake sediment anomalies.

At the Lac des Iles and Tib Lake study areas, results demonstrate that the levels of Ni, Cu and Cr in bog waters are significantly higher over the Mine Block intrusion (MBI) and the Tib intrusion compared to background areas. At the Baker zone of the Lac des Iles Mine, levels of these elements were even higher, evidence of hydromorphic dispersion from a point source of mineralization. The precious metals results show a similar but weaker pattern. Over prospective rocks, most levels are close to detection limits, whereas over background areas levels are dominantly below detection limit. At Lac des Iles, the same general pattern was observed from bog waters retrieved from sumps and from piezometers. This suggests that the use of piezometers to obtain bog waters is not critical, especially if no surface (or airborne) contamination is suspected within the area to be surveyed.

At the Cheeseman Lake and Circle Lake study areas, Cu displayed the best contrast between anomalous catchments and background areas. Gold levels within Cheeseman Lake anomalous catchments displayed good contrast to the background catchments, significantly better than at the Circle Lake study area. The metals Cr, Ni, Pd and Pt, at best, returned only a weak response within anomalous catchments compared to background.

At the Tarrison Lakes case study area, dissolved metals in bog water are very low, the lowest levels of all the case study areas. However, the metal levels in groundwaters obtained by piezometer are significantly higher. For example, the median (1.2 ppt) and average (1.3 ppt) levels of Pd in Badger Lake groundwater are approximately twice the levels found in Lac des Iles groundwater obtained by piezometer. Comparison of the 2003 Tarrison Lakes piezometer water data with the data from re-sampling in 2004 shows good reproducibility.

In summary, over areas with relatively thin drift and good geochemical contrast to background rocks (e.g., Lac des Iles and Tib Lake study areas), the base metal geochemistry of bog waters are significantly higher over mafic to ultramafic rocks compared to other (background) rock types. As a property-scale exploration tool, bog waters have excellent potential, providing that sufficient sampling is undertaken to reach "background" areas for comparison and contrast. As a regional (reconnaissance) tool, the cost effectiveness depends on adequate access to all catchment areas within the targeted survey area. The concurrent sampling of organic peat would increase the confidence level of the water chemistry and allow for the cost-effective analysis of precious metals. Bog water geochemistry is not as effective over areas with relatively poor geochemical contrast, such as on the Nipigon Embayment.

NATURAL SPRINGS AND OTHER TYPES OF GROUNDWATER

Groundwater samples were collected by several methods (e.g., sumps and piezometers in bogs, piezometers in dry creek beds, from the bottom of soil pits, from natural springs or seeps, boreholes). Comparing the geochemistry between samples collected by such different methods is difficult, if not impossible. In essence, each is a distinct media and should be treated separately. This is a key principle of surficial media geochemistry; failure to adhere to this principle can lead to false interpretations (e.g., false anomalies).

Outside of bogs, groundwater from natural springs was the most common type sampled. Eleven spring water samples were collected at the Circle Lake case study area, 6 at the Cheeseman Lake area, 2 at the Lac des Iles area and 1 each at the Tib Lake and Tarrison Lakes areas. In addition, 2 diamond-drill holes (DDH) collared on the Lac des Iles Baker zone and 2 soil pits at the Cheeseman Lake study area were sampled.

In waters pumped from diamond-drill holes located on the stripped Baker zone clearing at Lac des Iles, the levels of Cu and Ni were the highest compared to all other types of water samples (both surface and groundwater). The level of Cu in groundwater seeps on the flanks of the Baker zone are significantly lower than Ni; this likely reflects the significantly higher initial concentrations of Ni above Cu within mineralized rocks of the Baker zone (average Ni:Cu ratio of 3.8 to 1). The levels of the precious metals in groundwater are, on average, over twice as high as those for the bog water samples. However, the highest values occur in the waters from the 2 diamond-drill holes, water in direct contact with mineralized bedrock; levels drop off rapidly downslope away from mineralization.

At the Cheeseman Lake study area, almost all of the highest levels of Cu in water came from 4 springs and 1 soil pit located within the anomalous catchments. Water collected from the bottom of a soil pit near the background lake returned lower levels of most metals.

At the Circle Lake case study area, groundwater was sampled from 11 springs, all except one of which was located along the Thread Lake drainage. Groundwaters feeding the Thread Lake drainage are significantly higher in Cu (average 10 ppb) than surface waters, but levels of Pd and Pt are only marginally higher. The average level of Ni in these spring waters is no different than the stream water entering the Thread Lake drainage.

Several factors preclude the use of groundwater sampling for routine property-scale mineral exploration. These include, the inherent difficulty in finding sufficient sample sites for a statistically significant data set and the difficulty in interpretation if the waters are obtained by various methods. In some rare cases, the advantages of possibly detecting "blind" mineralization in areas of thick overburden may make this a viable sample medium.

Lake Water

A total of 53 samples of lake water were collected during the course of the project. Most of the samples were obtained in the Cheeseman Lake and Circle Lake study areas. Trace metal levels in dilute lake waters are typically very low, the lowest of all surface waters. In general, this limits their usefulness and cost effectiveness as an exploration tool; however, several interesting patterns emerged from the results of this study.

The average (9.3 ppb) and median (7.9 ppb) levels of Cu from 10 lakes sampled in the Cheeseman Lake case study area are the highest of the 5 case study areas. The levels of the other metals (Au, Ni, Co, Cr, Pd and Pt) were either below detection limits or too low to be significant compared to their estimates of precision. In order to maintain this level of Cu in the lake water, a significant flux of Cu must be moving into the lake basins.

A total of 28 lake waters were sampled in the Circle Lake case study area. Nickel and Pt are distinctly elevated along the Thread Lake and Pebble Lake drainages, compared to the rest of that study area. In fact, average Ni content of the sampled lake waters is the second highest of all the case study areas (after Lac des Iles). As at the Cheeseman Lake study area, the levels of the metals Au, Co, Cr, Pd and Cr are present at very low levels, often below detection limit.

At the Tarrison Lakes study area, the Pd results from Badger Lake are quite high for lake water; of 7 lake waters sampled across the Tarrison Lakes study area, only water from Badger Lake returned values above detection limit, ranging from 1 to 1.2 ppt. Only Shorty Lake and Walters Bog at Lac des Iles returned higher levels of Pd; however, it is likely that these water bodies are effected by airborne dust contamination.

These results demonstrate that lake waters can be useful to distinguish broad-scale geological features over bedrock-dominated terrain, where there is sufficient geochemical contrast between rock types. For example, the lake water results distinguished the Ni "elevated" upper sill, on the western side of the Circle Lake study area, from the diabase sill(s) on the east side.

The stream waters section (below) discusses the unique water chemistry imparted by the Seagull and Disraeli intrusions. Although lake waters were not sampled in the area of these intrusions as part of this study or the regional lake sediment survey (Dyer and Russell 2002), it is quite likely that a similar unique chemistry would be present. Therefore, over the Nipigon Embayment, hydrogeochemical methods could prove to be quite useful.

Table 2. Comparison of stream water geochemistry over the Circle Lake study area and over the Seagull–Disraeli intrusions.

Stream Waters (mean values)	**Au** (ppt)	**Ba** (ppb)	**Cr** (ppb)	**Cu** (ppb)	**Fe** (ppb)	**K** (ppb)	**Mg** (ppb)	**Ni** (ppb)	**Pd** (ppt)	**Pt** (ppt)	**Rb** (ppb)	**Sr** (ppb)	**pH**
Circle Lake area (n=74)	0.3	4.4	0.34	**5.1**	**723**	478	2621	1.1	1	0.2	0.8	12.7	7.1
Seagull–Disraeli intrusions (n=8)	0.1	16.9	**1.50**	2.6	440	1345	**7783**	**6.0**	1.4	0.1	4.9	20.0	7.2

Stream Water

In general, stream waters sampled over the Lac des Iles Mine Block intrusion and the Tib Lake intrusion do not have significantly higher levels of dissolved metals (Co, Cu, Ni, PGE, Au) than background areas. Only at the Mine Block intrusion does Cr in stream water display a clear signal distinctly above background levels (off the intrusion). Hydrogeochemistry of metals at the Road and Kuhner occurrences in the Tib Lake case study area, although at low levels, demonstrates hydromorphic dispersion is occurring. Chromium, Ni and Cu are present at levels greater than regional background near the Kuhner occurrence. At the Tarrison Lakes study area, most dissolved metal levels in stream waters are very low compared to the other study areas.

Within the Cheeseman Lake case study area, consistently elevated to anomalous levels of Cu occur in stream waters within the anomalous catchments. The average level of Cu is the highest of the case study areas, 3 times higher than at the Circle Lake case study area. Although displaying more variability, the highest levels of Au, Co, Ni and Pd also occur within the anomalous drainages. This contrasts with relatively low Au, Co, Cu, Pd and Pt levels that characterize most of the inlet streams to Danby Lake within the background catchment.

At the Circle Lake study area, the results for metals in stream waters show a similar pattern to that of the lake waters. Nickel and Pt are consistently elevated along the Thread Lake drainage system compared to the other catchments. Conversely, Co and, to a lesser degree, Cu, Pd and Au are elevated on the anomalous catchment on the east side of the study area. Mean and median levels of Cu are higher within the Circle Lake case study area than the Lac des Iles, Tib Lake and Seagull–Disraeli lakes areas, but much lower than the Cheeseman Lake area.

For comparison with the results at the Cheeseman Lake and Circle Lake study areas, an additional 22 stream waters were also collected in the area of the Seagull and Disraeli intrusions. Of these, 8 samples were identified as being underlain (and their upstream reaches) by Seagull or Disraeli intrusions. The average levels for selected elements for these 8 samples are shown in Table 2. While average pH is approximately the same, there are significant differences for a number of elements, in particular Cr, Cu, Ni and Mg.

Clearly, the chemistry of the Seagull and Disraeli intrusions are imparting a unique signature to the surrounding landscape, particularly in contrast to the surrounding ubiquitous (and often difficult to distinguish) Nipigon sill rocks. This contrast should confer an advantage to surficial geochemical methods, such as hydrogeochemistry (discussed here), and the existing regional lake sediment geochemical survey (discussed in the lake sediment section below), to map out the existence (and possibly areal extent) of Seagull-type intrusions.

The results of this study indicate that stream waters sampled over Archean bedrock-dominated terrain are generally low in dissolved metals except in fairly close proximity to mineral occurrences. This is in contrast with stream waters over Nipigon sill-dominated bedrock areas such as at Cheeseman and

Circle lakes. In these areas, the strong weathering characteristics of Nipigon sill and Sibley Group rocks have exacerbated both physical and hydromorphic dispersion in the surface environment.

Finally, comparison of the unique chemistry of stream waters in the Seagull–Disraeli intrusions area to those collected within the Cheeseman and Circle lakes areas indicates that it is unlikely that the sampied stream waters have come in contact with similar "Seagull"-type mafic to ultramafic intrusive rocks.

STREAM SEDIMENTS

Inorganic

The results of inorganic stream sediment sampling indicate this method is useful as a reconnaissance technique to distinguish broad geological features (e.g., Tib intrusion; nickel-enriched "upper" diabase sill at Circle Lake) and also useful on a property scale to vector upstream towards prospective areas that may have point-source mineralization. This is demonstrated at the Tib Lake study area where the highest levels of PGEs, Ni, Cu and Cr occur near the Kuhner occurrence. Another example is from the Cheeseman Lake area, where highly anomalous levels of Au, Cu and Pd at one stream sediment site vector to a possible source in one of the anomalous catchments.

The mean and median levels of Pd calculated from all of the sampled inorganic stream sediments are higher than for Pt:

	Pd (ppb)	**Pt (ppb)**
min	0.4	0.7
max	74.6	16.3
n	93	93
mean	**7.6**	**5.5**
median	**6.1**	**3.8**

(data shown determined by FA–ICP–MS)

This suggests that at least some Pd may be dispersed physically (clastic transport) as well as hydromorphically. The average loss-on-ignition (LOI) for the 93 samples was 12%; possibly, the presence of some fine organic material in many of these samples is the cause of the Pd level being higher that the Pt (hydromorphic transport and binding to organics). However, the stream sediment (fine silt) collected represent typical material easily obtained from creeks draining relatively flat shield terrain. Correlation coefficients are as follows (log transformed data):

Pd – Pt = 0.65
Pd – Cu = 0.79
Pd – Ni = 0.34
Pt – Cu = 0.78
Pt – Ni = 0.74
Pd – LOI = 0.10
Pt – LOI = –0.15

Good correlations between Pt and both of Ni and Cu, and between Pd and Cu demonstrate the potential of these base metals as pathfinders for PGE. Very poor correlations between Pd and Pt with LOI suggest that clastic transport of PGEs are the dominant mechanism of dispersion.

Comparison of the average abundances of the metals of interest in stream sediments between the case study areas reveals that inorganic stream sediment contains the highest levels of Cr in samples from the Lac des Iles and Tib Lake study areas. This reflects the presence of mafic to ultramafic intrusive rocks (Tib intrusion and the Lac des Iles Mine Block intrusion). As detailed in "Lake Sediment" below, Cr is potentially a very useful discriminator for the presence of such mafic to ultramafic intrusives, including Proterozoic Seagull-type intrusions. Because of this, and the fact that Cr travels dominantly by physical (clastic) transport, it is suggested that inorganic-rich sediment be target media for stream sediment surveys near and over the Nipigon Embayment.

Within areas of bedrock-dominated terrain, inorganic stream sediments are an effective and easily obtained sample media whose geochemical results reflect the composition of the geology (and possible mineralization) which lie upstream. This media has an application in both regional studies and for the follow up of lake sediment anomalies.

Organic

Organic-rich stream sediments were collected where available; in some cases, both organic-rich and inorganic samples were collected at the same site. Comparison of the data from organic-rich and inorganic samples collected at the Cheeseman Lake and Circle Lake study areas shows similar levels of Cu, Cr and Ni. Pt levels are usually higher in inorganic sediment, whereas Pd behaves erratically; at some sites, Pd is lower, at others, it is higher than in organic-rich sediment. Gold values are usually about the same or lower in inorganic sediment. Organic-rich samples collected at the Tib Lake study area have higher levels of Cu and Ni; levels of Pd are typically the same or higher in organic-rich sediment. Platinum levels are about the same in both organic-rich and inorganic sediment. Chromium is present at higher levels in inorganic sediment.

These results suggest that clastic (physical) transport is the predominant dispersion mechanism operating within the streams at the Cheeseman Lake and Circle Lake study areas. The level of organic matter in the sediment does not seem to have much effect on the metals of interest; therefore, variations in substrate composition are less critical during a sampling program. Conversely, at the Tib Lake study area, higher levels of Cu, Ni and possibly Pd in organic-rich sediment samples indicate that hydromorphic dispersion and transport is occurring. Significant differences in the levels in some of the metals of interest may be related to the relative amount of organic matter. Therefore, more care must be exercised in the Tib Lake area (and other areas or similar terrain) to obtain sediment samples with similar characteristics. As discussed in the previous section, since Cr is an important discriminator for the geochemical signal of ultramafic rocks, stream sediment sampling over Nipigon sills should focus on a consistent inorganic stream sediment media to maximize Cr levels and enhance contrast to background.

PEAT

A total of 80 peat samples obtained by auger were collected during this project. The majority of these samples were obtained from the Cheeseman Lake (n=23) and Lac des Iles (n=30) study areas. Samples were obtained near areas of known mineralization (Lac des Iles and Tib Lake study areas), from within lake sediment anomalous drainage catchments (Cheeseman Lake and Circle Lake study areas) and from background areas well away from known bedrock mineralization or lake sediment anomalies. Results demonstrate that the levels of the base metals of interest in organic peat are significantly higher over mafic to ultramafic intrusive rocks than background areas underlain by other rock types. Peat samples close to known mineralization at Lac des Iles and Tib Lake typically returned even higher metal levels. In general, Cu, Ni and Cr show the best response in terms of contrast and areal extent of anomalous values compared to samples obtained from background areas. The precious metals are also higher over PGE prospective rocks such as the Mine Block intrusion and Tib Lake intrusion, but not with the same reliability or consistency as the base metals.

At the Cheeseman Lake case study area, Au, Cu and Pd returned the best pattern in terms of contrast between the anomalous and background catchments. Nickel, Co and Cr values in peat are relatively low compared to the other study areas, but levels are higher within the anomalous catchments compared to background areas.

Compared to the Cheeseman Lake study area, the Circle Lake area peats have higher average levels of Ni, Cr and Pt, approximately the same levels of Au and Pd, but lower Cu levels. The most significant metal responses in peat obtained from within the anomalous catchments compared to the background sites were for Cu. Chromium and Co show no significant pattern or difference in levels between samples within anomalous catchments and those from background sites.

The average levels of Pd, Au and Cu in the peat samples from the Cheeseman Lake and Circle Lake study areas are much higher than at the Lac des Iles and Tib Lake study areas. This is due to several factors including the pervasive, relatively high background of these elements in the diabase sills, the landscape conditions (rugged bedrock-dominated terrain), the strong weathering characteristics of the diabase and, in the case of Cu, its high mobility in the surficial environment.

Nickel, Cu, Co and Cr in peat determined by Enzyme Leach^{SM} show a very distinct and consistent pattern of elevated to anomalous levels near known mineralization. Levels in background areas were consistently lower. This is good evidence for the presence of weakly bound (amorphous) metals hydromorphically dispersed from point sources. All Pt and Pd results by Enzyme Leach^{SM} were below detection limit (contrary to most of the FA–ICP–MS results) suggesting that these metals are associated with a phase for which the Enzyme Leach^{SM} is not strong enough to liberate. It is also possible that the lack of a precious metals response is an analytical issue.

Within the lake sediment anomalous drainage catchments at the Cheeseman Lake and Circle Lake study areas, Cu by Enzyme Leach^{SM} returned the most consistent anomalous levels compared to the background catchments. All Au, Pt and Pd results by Enzyme Leach^{SM} were below detection limit.

In summary, in the Lac des Iles and Tib Lake study areas, the metals geochemistry of organic peats are significantly higher over mafic to ultramafic rocks compared to over other (background) rock types. The results of peat geochemistry over the Nipigon sills show good contrast between anomalous and background catchments, but is not as effective for all the metals of interest (e.g., Cr). As a property-scale exploration tool in the Lake Nipigon area, peat has excellent potential, especially in areas with abundant organic terrain. As a regional (reconnaissance) tool, to identify anomalous catchments related to prospective bedrock, the cost effectiveness depends on adequate access to all catchment areas within the targeted survey area. The use of peat for lake sediment anomaly follow up is warranted, particularly in tandem with other media such as soils. In low-relief shield areas, peat is often very abundant and quickly and easily obtained. Organic-rich media, such as peat, act as a "sink" and easily bind and accumulate hydromorphically dispersed metals. As with all surficial media sampling for geochemical purposes, sampling should extent to areas beyond the area of immediate interest (into "background" areas) for contrast and comparison.

LAKE SEDIMENT

Lake sediments were sampled as part of this project primarily to fill gaps in the current coverage within the case study areas. The majority of samples were collected from the Circle Lake study area, but at least one sample was collected from every case study area. At Circle Lake, the original Pt and Ni anomalies in lake sediment along the Thread Lake drainage were replicated and additional lakes highly anomalous for Cu were found in the anomalous catchments to the east.

At Lac des Iles, lake sediment samples were obtained from Walters Bog, which is located approximately 600 m from the original Roby PGE occurrence, and approximately the same distance from the Baker zone. The results for Pd, Pt and Au from deep sediment (>20 cm) were 5.4, 0.8 and 3.5 ppb, respectively. These levels are roughly half as high as the results obtained from Shorty Lake deep sediment (Pd=13.6, Pt=3.6 and Au=5). This drop in geochemical intensity with distance may be a useful and important guideline for explorationists utilizing lake sediment geochemistry.

The Tib Lake area has occurrences of Cu-Ni-PGEs in bedrock, but virtually no lake sediment anomalies. However, careful examination of the regional lake sediment data reveals that the levels of Ni, Cr and Cu in lake sediment over the intrusion are, on average, higher than the adjacent areas underlain by granitic rocks. The presence of significant glaciofluvial sand over the Tib intrusion may also be playing a role in diluting the signature of the metals of interest. The lack of lake sediment Cu-Ni-PGE anomalies over the southern portion of the Tib intrusion ("Lower Border zone") is likely due to a paucity of lakes in this area, which hosts most of the known occurrences. Only 2 water bodies have Lower Border zone rocks within their drainage catchments; one of these is the East Dog River, which is mostly bottomed by inorganic sediment.

Re-sampling of lake sediment at Badger Lake, in the Tarrison Lakes case study area, was completed by boat, including both shallow and deep sediment. The sediment was noted to have a distinct H_2S odour, likely due to anaerobic bacteria. Such anaerobic conditions, with the attendant formation of H_2S, and the presence of alkaline water (surface water pH = 8.5; at the bottom pH = 7.6), results in most metals partitioning into the sediment rather than going into solution. Regardless of the source of the metals in this lake, the levels have been exacerbated by the limnological conditions of the lake.

Available regional lake sediment data (NGR and OGS data sets) demonstrate the effectiveness of lake sediment geochemistry as a reconnaissance exploration method. In particular, patterns for the elements Cr, Ni and Pt clearly distinguish the presence of the Lac des Iles mafic to ultramafic complex from the surrounding rock types. Geochemical patterns of Cu and Pd are not as effective in distinguishing the Lac des Iles complex due to the widespread presence of Nipigon diabase rocks (particularly up-ice), which have a natural high background of Cu and Pd relative to most other rock types in the area. The combined results of these lake sediment surveys have demonstrated that the Nipigon Embayment rocks (especially diabase) are contributing high levels of several metals, in particular Cu, to the lake basins. Of particular exploration interest has been the anomalous levels of Pd and Pt present in many of the lake bottom sediments.

The Seagull and Disraeli intrusions are also contributing a unique chemistry to the landscape; the results of stream water sampling demonstrate this (*see* "Stream Waters" above). This unique chemistry should also be reflected in the lake sediment results. To test this, statistics were calculated from 15 lake sediment samples from the regional survey (Dyer and Russell 2002) located on or adjacent to the Seagull, Disraeli and Hele intrusions. The most recent bedrock mapping by Hart and Préfontaine (2004) was used to determine the most appropriate lake sites. These data are shown in Table 3 and are compared to the lake sediment results for 900 lake sediment samples (Dyer and Russell 2002) underlain predominantly by

Table 3. Lake sediment geochemistry over Nipigon diabase sills compared with lake sediment geochemistry over the Seagull, Disraeli and Hele intrusions.

Method:	**Cr** (ppm) ICP-MS	**Ni** (ppm) ICP-MS	**Co** (ppm) ICP-MS	**Au** (ppb) INAA	**Pt** (ppb) FA-ICP-MS	**Cu** (ppm) ICP-OES	**Sm** (ppm) ICP-MS	**Zn** (ppm) ICP-MS	**La** (ppm) INAA	**Mg** (ppm) ICP-MS	**Ca** (ppm) ICP-OES	**U** (ppm) ICP-MS
Nipigon sills (n=900)												
Mean	18.1	26.2	8.9	2	2.4	130	3.3	83	16	3535	**13560**	**3.0**
Median	15.2	23.6	7.3	3	2.1	95	2.8	76	15	2471	9482	1.0
Seagull, Disraeli, Hele intrusions (n=15)												
Mean	**93.2**	**98.1**	**21.9**	**6**	**5.4**	**189**	**4.8**	**120**	**24**	**5097**	8412	1.1
Median	90.7	74.2	16.7	7	5.3	195	4.0	116	24	3765	8345	0.8
difference of means (%)	81	73	59	58	56	31	31	31	31	31	–61	–163

Nipigon sills in the surrounding area. The order of the elements in this table was determined by the largest percent difference in average levels for each element. Chromium and Ni show the largest differences in average concentration between areas underlain by Nipigon sills and Seagull-type intrusions. Because high levels of Ni in lake sediment do occur locally, for example, at the western side of the Circle Lake study area, due to naturally high levels in the "upper" Nipigon diabase sill, Cr would appear to be the more reliable "filter" for discriminating between lake sediment geochemistry due to Nipigon diabase sills and that due to Seagull-type intrusions.

In addition, when Gd/Yb ratios in lake sediment collected for the regional Lac des Iles–Black Sturgeon River area are superimposed over the geology, the results show that the Seagull, Disraeli and Hele areas have very high values compared to the lakes underlain by Nipigon sills. This may be an additional discrimination method that, if used in conjunction with Cr, may be highly effective for pinpointing similar "Seagull"-type intrusions elsewhere on the Nipigon Embayment.

Nickel-Copper-Platinum Group Element Exploration Using Surficial Media: Observations, Recommendations and Exploration Methodology

Based upon the data collected from this study, a number of observations and recommendations can be put forward to assist explorationists with PGE exploration in glaciated terrain, the use and interpretation of lake sediment data, and appropriate methods for follow up. These are

- Over Archean terrane, there is often excellent geochemical contrast between the target intrusive rock type (mafic to ultramafic) and surrounding rock type (e.g., granitic rocks). This geochemical contrast is mirrored in the geochemistry of most surficial media sampled during this project. In addition, visually similar (but chemically or mineralogically distinct) rocks can be discerned through surficial media sampling (e.g., chrome andradite garnets in till at Lac des Iles). As a rule, surficial geochemical sampling should be extended into "background" areas to properly compare, contrast and identify anomalies that may vector to prospective rocks or mineralization.

- Over Nipigon sills, the geochemical contrast is much weaker for Cu, Pd and Au due to a relatively high background in the sills. Readily weathered (and locally intensely weathered) diabase in bedrock-dominated terrain results in an enhanced (apparently "*anomalous*") geochemical signal for Cu and Pd. "Seagull"-type intrusions share similar weathering characteristics; therefore, explorationists need to focus on the geochemical differences between the diabase sills and the mafic to ultramafic intrusive rocks of interest.

- A prudent exploration strategy for PGE mineralization should include targeting the associated metals (Cu, Ni, Cr) to vector to prospective ground prior to detailed work involving the determination of PGEs and/or indicator minerals in surficial media. Relative to the metals Cu and Ni, the PGEs have significantly lower initial concentrations (ppb levels), are much less mobile in the surficial environment and are less reliably determined at the laboratory (poorer reproducibility in part due to classic "nugget effect"). Therefore, to a great degree, exploration for PGEs using surficial media is very much a sampling issue and problem. The absence of a PGE response in surficial media, or the absence of PGE indicator minerals in a sample should not and cannot immediately rule out an area from exploration consideration.

- Well-defined geochemical dispersal trains were observed in sample results of C-horizon till and heavy mineral concentrates of the till, particularly at Lac des Iles, where sampling density was sufficient. Dispersal trains for PGEs were found to be short, however, the trains of associated elements such as Ni and Cu are much larger and provide a much bigger target area for mineral exploration. Regional sampling provides information on regional dispersal and will help in defining areas of interest for follow-up sampling. C-horizon till is the first derivative of the bedrock. If the direction of last movement is known, then it can be used to trace elements, mineral and/or rock fragments back to their source. In the Nipigon area, samples should be collected at depths greater than 50 cm to obtain C-horizon material.

- The behaviour of Ni in the soil environment is similar to that of Pt and can be used as a proxy under most conditions (possibly except for carbonate-rich environments?) for geochemical exploration. In areas of elevated pH, Ni does not appear to be as mobile as Pt and, therefore, their pathways through the soil environment diverge. The behaviour of Cu in the soil environment is similar to that of Pd with respect to relative mobility.

- Quality control begins in the field during a sampling program by consistently applying an appropriate methodology in the collection of the targeted sample media. A critical aspect of surficial media geochemistry can be summed by the adage, "compare apples to apples". For example, shallow groundwaters collected by piezometer are a distinct type of sample media that cannot be directly compared to surface waters (e.g., stream water). Each distinct type of media should be treated separately. This is a key principle of surficial media geochemistry; failure to adhere to this principal can lead to incorrect interpretations (e.g., false anomalies).

- Caution should be used when sampling and interpreting B-horizon samples in areas of Type 5 geochemical soil profiles (Klassen 2003). B-horizon results should only be compared where the **parent material (C-horizon) is similar**. This is a particular problem in areas of thin glacial sediments overlying Nipigon sills and in areas that contain a variable thickness of glaciolacustrine sediments over till or rock.

- Property-scale geochemical exploration methods for PGE-bearing deposits should include media that target hydromorphically dispersed Ni and Cu. Even low sulphide (<5%) bearing rocks contribute a significant and easily measurable geochemical footprint in waters and surficial media. The geochemical footprint of hydromorphically dispersed PGEs from mineralization is relatively short compared to Cu and Ni. This is evident at both Tib Lake and the Lac des Iles study areas.

- The results of stream water sampling show that the Seagull and Disraeli intrusions impart a unique signature (e.g., Cr, Ni and Mg) to the surrounding landscape, particularly in contrast to the surrounding ubiquitous (and often difficult to distinguish) Nipigon sill rocks. Similar geochemical contrasts probably exist in other types of surficial media; knowledge of which could be exploited for effective exploration for "Seagull"-type intrusions elsewhere on the Nipigon Embayment. Stream water hydrogeochemistry may be advantageous for this purpose as it is easily collected and the appropriate trace (e.g., Cr, Ni) and major elements (e.g., Mg) can be analyzed relatively cheaply, without complicated or expensive field handling techniques.

- Available regional lake sediment data (NGR and OGS data sets) demonstrate the effectiveness of lake sediment geochemistry as a reconnaissance exploration method. In particular, patterns for the elements Cr, Ni and Pt clearly distinguish the presence of the Lac des Iles mafic to ultramafic complex from the surrounding granitic terrain. Geochemical patterns of Cu and Pd are not as effective in distinguishing the Lac des Iles complex due to their relative ease of mobility (Cu >Ni and Pd > Pt) and the widespread presence of Nipigon diabase rocks (particularly up-ice), which have a natural high background of Cu and Pd relative to granitic rocks.

- On the Nipigon Embayment, the Seagull, Disraeli and Hele intrusions, while not always visually distinct from Nipigon diabase sills and dikes, are geochemically distinctive; in particular, rare earth element ratios such as Gd/Yb are used to discriminate between the 2 rock types. This discrimination technique applied to regional lake sediment geochemistry shows that Gd/Yb ratios are significantly higher over the Seagull, Disraeli and Hele intrusions compared to the surrounding diabase sills. On average, Cr and Ni are also significantly higher over these "Seagull"-type intrusions relative to the diabase sills. Because Ni is elevated in some Nipigon diabase intrusions, such as on the west side of the Circle Lake study area (which is reflected in the adjacent lake sediments), Cr may be the better element to use, in conjunction with REE ratios (e.g., Cr × Gd/Yb), for applying this discrimination technique on lake sediment geochemistry elsewhere on the Nipigon Embayment.

- Results of sampling and analysis (FA–ICP–MS on –80 mesh) of stream sediment demonstrate that Pd (mean = 7.6 ppb) is present in comparable quantities to that of Pt (mean = 5.5 ppb). Good correlations between Pt and Ni and Cu with Pd again demonstrate the potential of these metals as pathfinders or proxies for PGE. Since chromium is a very useful and important discriminator of ultramafic intrusive rocks (both Archean and Proterozoic age), it is recommended that inorganic sediment (which on average has higher levels of Cr) be the preferred media for stream sediment surveys, particularly near and over the Nipigon Embayment

- Evidence from this study suggest that some base metals (such as Cu and Ni) are elevated in surface bog water relative to deeper bog water. It is unclear if this phenomenon is due to an anthropogenic (airborne) flux, higher levels of organic matter, biological activity or Fe and Mn at or near the surface, which may complex and scavenge metals. As a result, surface bog waters should be treated as a separate media type from other types of surface waters and deeper bog waters (such as obtained by piezometers).

- Ashed ICP for PGEs and base metals do not show the level of reproducibility and contrast that conventional methods (fire assay and direct aqua-regia digestion ICP) show.

- In bedrock-dominated and thin drift areas, metals of interest in peat determined by Enzyme Leach^{SM} show excellent contrast to background areas: Ni is best, followed by Cu, then Cr. However, precious metals determined by this method are very low, usually below detection limits.

- In general, hydromorphic metals dispersion downslope from a point source increases in terms of distance and level of concentration with increasing slope. This has implications on the interpretation of geochemical surveys on both the property scale (humus, stream sediments) and regional scale (lake sediments).
- Geochemical results suggest that the metals (Ni, Cu, PGEs) tenor at the Tib intrusion is generally low. From a regional standpoint, the geochemical footprint of the intrusion is much smaller than that at Lac des Iles; however, detailed sampling (peat, stream sediments, waters) near the occurrences demonstrate that these conventional geochemical methods do work, in this case, more at the property scale, in the absence of suitable or accessible soil or till exposures.
- Lakes in bedrock-dominated areas, especially in areas of rugged topography, can have an enhanced geochemical (metals) signal compared to lakes with a significant fringe of organic (swamp) terrain. Intervening organic-dominated landscape acts to "decouple" the bedrock geochemical signal from the lakes (and sediment). This also applies to rivers, which can be effectively "decoupled" from the geochemical signal of the bedrock valley walls by wide organic-rich floodplains. An assessment of landscape conditions is required to decide appropriate sampling strategies which may require a multi-media approach (e.g., soils and peat).
- Table 4 is a listing of various types of surficial media with comments regarding their usefulness and cost effectiveness for mineral exploration.

METHODOLOGY FOR FOLLOW-UP OF LAKE SEDIMENT ANOMALIES USING SURFICIAL MEDIA

PGE lake sediment anomalies located on the Nipigon embayment should be screened by examining Cr and REE data. The level of Cr in lake sediment underlain by Nipigon sills and Sibley Group sedimentary rocks is almost always less than 40 ppm (average of 18 ppm). The level of Cr in lake sediment underlain by Proterozoic "Seagull"-type intrusions is almost always greater than 40 ppm (average of 93 ppm). As an additional discrimination method, the REE ratio of Gd/Yb in lake sediment can be used. Lake basins with significant "Seagull"-type intrusions within their drainage catchments have Gd/Yb ratios above 3.0. Combining these 2 parameters is most effective; values of the product of Cr (ppm) times the Gd/Yb ratio that exceed the 95th percentile should be focused on. This method was tested on the OGS regional lake sediment data (Dyer and Russell 2002) and clearly distinguishes the presence of the Proterozoic Seagull, Disraeli and Hele intrusions from the surrounding Nipigon sills and Sibley Group sediments. **This discrimination method will only work for lake sediments collected from the Nipigon Embayment, to help distinguish the presence of Proterozoic "Seagull"-type intrusions from Nipigon diabase sills and Sibley Group rocks.**

A suggested methodology for the following up lake sediment anomalies would include the following steps:

1. define drainage catchment area for lake with anomalous values.
2. identify focal points for sediment and water inputs into lake basin (streams, creeks and springs):
   a) **if** abundant, then sample up creeks (water, sediment, peat);
   b) **if** results (stream water and/or sediment) vector upstream to the next lake basin, return to step 1;
   c) **if** stream density is low, or negative response from step a), then alternatively **or** in addition go to step 3.
3. a) determine degree of glacial sediment cover (sediment versus bedrock);
   b) determine type of sediment cover (till, peat, rock and other) and distribution.

Table 4. Summary table of types of surficial media with comments regarding the usefulness and cost-effectiveness for mineral exploration.

	Media	Scale	Usefulness	Costs	Remarks
Archean bedrock terrain continuous to near continous cover of till					
till	HMC	regional and property	moderate	high	however may narrow target area substantially with the presence of PGMs or associated minerals
till	C-horizon till	regional	high	low	excellent method to narrow down areas of interest
till	C-horizon till	property	high	low	excellent method to vector to source
soil horizon developed in till	B-horizon till	regional	low	low	not very useful at this scale
soil horizon developed in till	B-horizon till	property	moderate to high	low	useful for targeting heads of dispersal trains
soil horizon developed in rock	residual soil	regional and property	limited	low	media not commonly abundant in Archean bedrock terrain
organic-rich soil horizon	humus	regional	low	low	not very useful at this scale
organic-rich soil horizon	humus	property	moderate to low	low	can be useful for targeting heads of dispersal trains
peat	peat	regional	low	low	not very useful at this scale
peat	peat	property	moderate to high	low	sufficient sampling should be undertaken to reach "background" areas for comparison and contrast
stream sediment	fine fraction (silt, fine sand)	regional	moderate to high	low	good for targeting areas for follow-up, suitability depends on density of drainage network/availability of sample sites
stream sediment	fine fraction (silt, fine sand)	property	high	low	Good to target areas/excellent to follow-up lake sediment anomalies; relative level of organic matter can influence metal levels
lake sediment	lake sediment	regional	high	low	Excellent method to identify areas of interest for follow-up, suitability depends on density of lakes
lake sediment	lake sediment	property	low	low	not very useful at this scale
surface water	stream water	regional	low to moderate	moderate	suitability depends and density of drainage network and pH conditions; not useful in areas of carbonate rich till (alkaline pH)
surface water	stream water	property	moderate to low	moderate	suitability depends and density of drainage network and pH conditions; not useful in areas of carbonate rich till (alkaline pH)
surface water	lake water	regional	low	moderate	dilute waters have low levels of metals, poor anomaly to background contrast; not useful in areas of carbonate rich till (alkaline pH)
surface water	lake water	property	low	moderate	dilute waters have low levels of metals, poor anomaly to background contrast; not useful in areas of carbonate rich till (alkaline pH)
groundwater	ground water (springs)	property	low to moderate	moderate	adequate sample density possibly difficult to achieve; potential for false anomalies if compared to other types of (surface) water
groundwater	bog water (piezometer)	property	moderate to low	moderate	naturally turbid water increases filtering costs, effective tool for base metals; concurrent sampling of organic peat recommended
shallow groundwater	bog water (dug sump)	property	low to moderate	moderate	naturally turbid water increases filtering costs; prone to surface (airborne) contamination; concurrent sampling of organic peat recommended
Nipigon Sill upland areas with discontinuous cover of thin till					
till	HMC	regional and property	low to moderate	high	however may narrow target area substantially with the presence of PGMs or associated minerals
till	C-horizon till	regional and property	low to moderate	low	obtaining appropriate sample distribution can be a problem
soil horizon developed in till	B-horizon till	regional	low	low	problems in obtaining sample distribution and mixing results from multiple parent materials
soil horizon developed in till	B-horizon till	property	moderate	low	problems in obtaining sample distribution and mixing results from multiple parent materials
soil horizon developed in rock	residual soil	regional	low	low	problems in obtaining sample distribution and mixing results from multiple parent materials
soil horizon developed in rock	residual soil	property	moderate	low	problems in obtaining sample distribution and mixing results from multiple parent materials
organic-rich soil horizon	humus	regional	low	low	problems with mixing results of humus developed over different parent material
organic-rich soil horizon	humus	property	moderate	low	problems with mixing results of humus developed over different parent material
peat	peat	regional	low	low	not very useful at this scale
peat	peat	property	moderate	low	Potential for locally enhanced Cu-Pd-Au signal due to deep weathering of Nipigon sills
stream sediment	fine fraction (silt, fine sand)	regional	moderate	low	potential for false anomalies due to local regolith/residual soil rich substrates; suitability also depends on density of drainage network
stream sediment	fine fraction	property	moderate	low	potential for false anomalies due to local regolith/residual soil rich substrates; suitability also depends on

	Media	Scale	Usefulness	Costs	Remarks
	(silt, fine sand)				density of drainage network
lake sediment	lake sediment	regional	high	low	Caution due to locally enhanced Cu-Pd signal from deeply weathered Nipigon sills; Use Cr and REES to screen anomalies
lake sediment	lake sediment	property	low	low	not very useful at this scale
surface water	stream water	regional	moderate to low	moderate	Mg, Cr and Ni may be useful to detect presence of ultramafic rocks, dependant on density of drainage network and pH conditions
surface water	stream water	property	low to moderate	moderate	Mg, Cr and Ni may be useful to detect presence of ultramafic rocks, dependant on density of drainage network and pH conditions
surface water	lake water	regional	low	moderate	dilute waters have low levels of metals; poor anomaly to background contrast
surface water	lake water	property	low	moderate	dilute waters have low levels of metals; poor anomaly to background contrast
groundwater	ground water (springs)	property	low to moderate	moderate	adequate sample density possibly difficult to achieve; potential for false anomalies if compared to other types of (surface) water
groundwater	bog water (piezometer)	property	moderate to low	moderate	naturally turbid water increases filtering costs; effective tool for base metals; concurrent sampling of organic peat recommended
shallow groundwater	bog water (dug sump)	property	low to moderate	moderate	naturally turbid water increases filtering costs; prone to airborne contamination, concurrent sampling of organic peat recommended
Areas of thick glaciofluvial deposits (not an area or material recommended to sample, only if required to follow-up lake sediment anomalies)					
till	HMC	regional and property	low	high	not very useful in this setting, vectoring to source difficult
till	C-horizon till	regional	low to moderate	low	may help in vectoring away from area (landfrom)
till	C-horizon till	property	low	low	not very useful in this setting, vectoring to source difficult
soil hoizon developed in till	B-horizon till	regional and property	low	low	not very useful in this setting, vectoring to source difficult
sand and gravel	C-horizon sand	regional	low to moderate	low	however knowing paleoflow directions important inorder to vector to source
sand and gravel	C-horizon sand	property	moderate	low	however knowing paleoflow directions important inorder to vector to source
soil hoizon developed in sand and gravel	B-horizon sand	regional	low	low	however knowing paleoflow directions important inorder to vector to source
soil hoizon developed in sand and gravel	B-horizon sand	property	low to moderate	low	however knowing paleoflow directions important inorder to vector to source
soil horizon developed in rock	residual soil	regional and property	limited	low	media not commonly abundant in areas of thick glaciofluvial deposits
organic-rich soil horizon	humus	regional and property	low	low	difficult to vector to source and recognize anomalies
peat	peat	regional	low	low	not very useful at this scale
peat	peat	property	low to moderate	low	thick peat accumulations difficult to find, samples easily contaminated with inorganics, potential for false anomalies (*see* Hamilton et al. 2005)
inorganic stream sediments	stream sediments	regional and property	low	low	geochemistry primarily reflects composition of exotic overburden therefore very difficult to vector to source and recognize anomalies
organic stream sediments	stream sediments	regional and property	low	low	difficult to locate suitable sample material
lake sediments	lake sediments	regional and property	low to moderate	low	depends on drift thickness; thick glaciofluvial deposits will provide dominant geochemical signal, masking response from other sources
surface water	stream water	regional and property	low	moderate	geochemistry primarily reflects composition of exotic overburden therefore very difficult to vector to source and recognize anomalies
surface water	lake water	regional and property	low	moderate	dilute waters have low levels of metals, geochemistry primarily reflects composition of exotic overburden; difficult recognize anomalies
shallow ground water	groundwater (piezometer)	regional and property	moderate	moderate	potentially useful on property scale if sufficient sampling undertaken and drift thickness is not extreme
shallow ground water	bog water (piezometer)	regional and property	low to moderate	moderate	potentially useful on property scale if sufficient sampling undertaken and drift thickness is not extreme
shallow groundwater	bog water (dug sump)	regional and property	low	moderate	near surface water typically too dilute, metals at/near detection limits, difficult to locate suitable sites, therefore poor sample density

4. consider groundwater flow paths throughout catchment basin and determine proportion of flow path lengths through till areas and rock areas:
   if high proportion is in till areas then C-horizon till sampling is recommended combined with peat sampling of bogs and swamps;
   if considerable flow paths are over bedrock areas (e.g., in the Cheeseman Lake and Circle Lake areas) then may not have to sample till, however, possible important information may be missed.

5. For till sampling, C-horizon till samples are recommended based primarily on the principle that erosion and dispersal of mineralization by glaciers provides a bigger preliminary target for prospecting than the mineralization itself. Soil-forming processes extend to depths of 40 to 60 cm in the Nipigon Embayment area, so to obtain C-horizon till samples, samples should be collected below these depths. Once the train has been intersected, sample in the up-glacier flow direction until the train terminates and this should correspond to the area of mineralization.
   Samples from the Bf horizon of soils developed in till (collected between 10 to 20 cm depth) are also useful for follow-up work at the property scale to pinpoint the head of the dispersal train and mineralization.
   Care should be taken to only sample till, material deposited directly from a glacier with little or no reworking by water.

Caution: when sampling B-horizon or humus, determine parent material, and compare sample results with samples derived from the same parent material separately.

METHODOLOGY FOR PLATINUM GROUP ELEMENT EXPLORATION USING SURFICIAL MEDIA IN AREAS OF MAFIC TO ULTRAMAFIC INTRUSIONS

A suggested methodology for using surficial media in areas of mafic to ultramafic intrusions would include the following steps:

1. determine degree of glacial sediment cover (sediment versus bedrock).
2. determine type of sediment cover (till, peat, rock and other) and distribution.
3. determine direction of ice movement:
   if high proportion of till areas, then C-horizon till sampling is recommended combined with peat sampling of bogs and swamps; see notes regarding till sampling in section 5 above;
   if the area is bedrock dominated and there is a lack of suitable till for sampling, then may not have to sample till, however, possible important information may be missed.
4. **Where** rivers or creeks and wetlands are abundant, then determine catchment boundaries and sample stream sediments and peat to appropriate density to suit the scale of exploration.
   if streams and wetlands density is low, then disregard these methods of sampling except at the property scale. Consider regional soil (till) sampling survey.
5. In addition, consider groundwater flow paths throughout catchment basin and determine places where it reaches the surface, such as in springs, streams or swamps, and sample the appropriate media there, the preference is to sample organic-rich material when exploring for PGE or their associated elements (Ni, Cu, Cr, Mg, Co).

RECOMMENDED LABORATORY ANALYSIS METHODS FOR PLATINUM GROUP ELEMENT EXPLORATION

Waters: ICP–MS scan for >30 elements; major, minor and trace elements (not Au or PGEs).

Stream sediment: total (multi-acid-HF) digestion-ICP–MS–OES; optional: FA–ICP–MS analysis for Au and PGEs (30 g subsample).

Peat or humus: aqua-regia digestion ICP–MS–OES; optional: weak partial extraction (e.g., Enzyme Leach^{SM}) for base metals; optional: FA–ICP–MS analysis for Au and PGEs (10 g subsample).

Soil ("B" and "C" horizon) samples analyzed by total (multi-acid-HF) digestion-ICP–MS–OES and FA–ICP–MS (30 g subsample) for Au and PGEs.

Case Study Area Results

LAC DES ILES STUDY AREA

Introduction

The Lac des Iles study area is in a bedrock-dominated terrain underlain by ultramafic to mafic intrusive rocks, commonly gabbro. It is the only case study area that contains an operating palladium-platinum mine. The terrain is a regional area of high elevation and has local relief of over 60 m. A map of the distribution of surficial sediments is presented as Map 1 (back pocket).

The bedrock surface, where recently exposed, is commonly well polished, striated and contains large-scale meltwater erosion marks such as transverse troughs and cavettos. Weathered or long-exposed bedrock surfaces tend not to retain the striation record due to their coarse-grained nature. The dominant direction of ice flow recorded from striae is toward 240°, however, variation in striae orientation ranges from 225 to 245° (Photo 3). One area at the northeast end of the Baker zone has striae oriented between 180 and 190° (Photo 4). It lies in the lee of a large bedrock knob, an area protected from a younger glacial event that flowed to the southwest (240°).

Till is the material directly deposited by the glacier with little or no reworking by water (Dreimanis 1989). Till was not found in association with the older direction of ice movement. Till associated with the younger, dominant ice flow direction is common, but thin, usually less than 3 m. It thickens on the flanks and in the down-ice direction from bedrock knobs. It is usually a massive to fissile, stony, slightly silty, very fine- to coarse-grained sand. Analysis of 21 samples of till (C-horizon) average approximately 70% sand, 29% silt and 1% clay-size particles in the matrix. Several well-developed crag-and-tail features occur in the Creek zone. Their orientations compare favourably with that of the striations on the bedrock surface (235 to 242°). An actively flowing wet-based glacier deposited the till in the Lac des Iles area. The extensive record of striae, the large-scale meltwater erosion features and the common occurrences of interbedded stratified sediments and till in lee-side cavity fills support this conclusion.

Stratified glaciofluvial sand and gravel is found in large and small sinuous ridges (eskers) and in small lee-side cavity fills within the Lac des Iles area. Sand of glaciolacustrine origin occurs beneath small plains in low elevation areas along the southern shore of Lac des Iles.

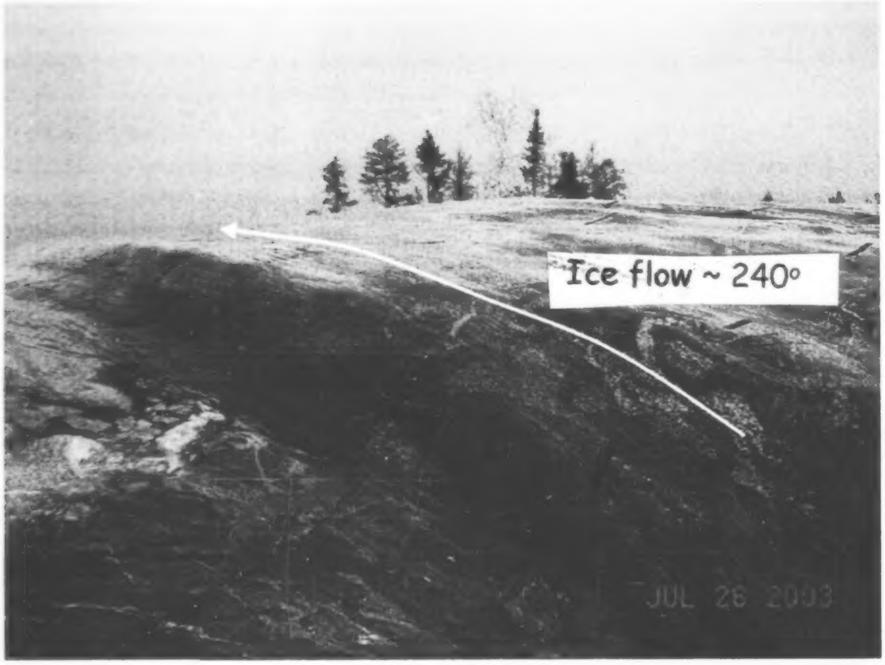

Photo 3. Striated and polished bedrock surface at Baker zone, Lac des Iles area.

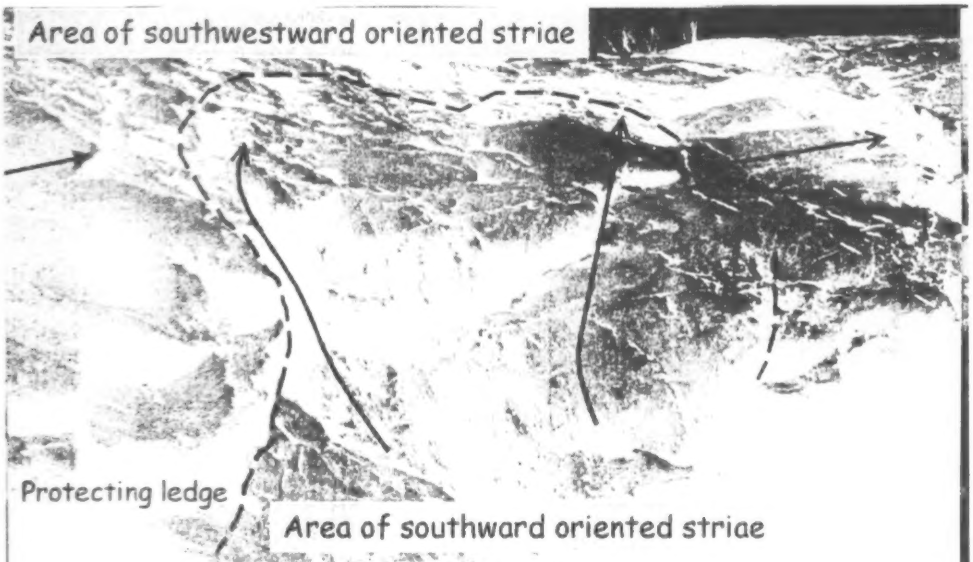
Area of southwestward oriented striae
Protecting ledge
Area of southward oriented striae

Photo 4. Preserved, older 180° striae protected by bedrock knob, Baker zone, Lac des Iles area.

Soils developed in till in the Lac des Iles area generally consist of a very thin humus layer commonly containing charcoal, a thin to nonexistent zone of eluviation (Ae), usually less than 1 cm thick, and a B-horizon 30 to 50 cm thick. The B-horizon consists of a 10 cm dark orange brown Bf-horizon that is enriched in iron and a 20 to 40 cm thick yellow-brown to brown Bm- and/or BC-horizon. Silt and clay content of B-horizon samples derived from till contain more silt- and clay-size particles than the parent material (C-horizon). This is due to the breakdown and relocation of particles of the original parent material by soil forming processes. Analysis of 21 B-horizon till samples average about 56% silt and 4% clay, an increase of about 30% of these fine-textured components. The parent material or C-horizon tends to be grey in colour. Most "C-horizon" samples collected and reported by Searcy (2001) appear to have been from the lower part of the B-horizon and the "B-horizon" samples from the Bf-horizon. The data presented herein are, therefore, not necessarily directly comparable.

Till: Glacial Dispersal

The Lac des Iles area is well suited for the use of till in mineral exploration. Dispersal trains or plumes can be observed in both heavy mineral (chromites and chrome andradite garnite) and till (C-horizon) geochemistry results (Ni, Cr, Cu and Co).

HEAVY MINERAL RESULTS

Six samples from the Lac des Iles area were processed and analyzed for heavy minerals by the Ontario Geoscience Laboratories (GeoLabs), Ministry of Northern Development and Mines, to obtain the overall heavy mineral assemblage in till from this area. The average heavy mineral composition consists of about 71% clinopyroxene, 9% calcic amphibole, 7% orthopyroxene and minor amounts (<2%) of chromite, forsterite, fayalite, epidote and chrome andradite garnets. These minor constituents are of interest in mineral exploration (Averill 2001).

In addition, 28 heavy mineral samples were processed and analyzed by Overburden Drilling Management Limited (ODM) of Nepean, Ontario. The methodology followed was developed at ODM and has been summarized in several publications (Morris and Kaszycki 1997; Averill 2001; McMartin and McClenaghan 2001). The reports provided by ODM concentrate on the important minor constituents or indicators of mineralization of the heavy mineral assemblages. The results provided by ODM are contained in MRD 154. Samples collected previously by C.A. Searcy and analyzed by ODM (Searcy 2001) are used in the current study to help define dispersal trains.

Overburden Drilling Management Limited recognized several mineral assemblages within the Lac des Iles set of samples. The assemblages were dominated by pigeonite and included chrome andradite garnet, diopside and/or epidote.

Platinum Group Minerals

Very few heavy mineral grains containing platinum or palladium have been reported from the Lac des Iles area. Searcy (2001) reported one sperrylite ($PtAs_2$) grain (00-CAS-4354) down ice-flow direction of the Powerhouse zone and, during the current study, 2 stillwaterite (Pd_8As_3) grains were recovered from sample 03-PJB- 109 (or Lac-Soil 023) located southwest of the Baker zone.

Searcy (2001) reported 2 native platinum grains from the Legris Lake property and 2 sperrylite grains from the Nym Lake area in her study on drift exploration for platinum group elements in northwestern Ontario. Tardif (2000) reported 16 sperrylite grains and one stibiopalladinite (Pd_5Sb_2) grain from 9 till sample sites collected down ice-flow of known mineralization at the Dana Lake and Azen Creek zones in the River Valley area, northeast of Sudbury, Ontario. Despite the low numbers of recovered grains, their occurrence is considered important and the presence of any of these platinum group minerals indicates that mineralization may be located nearby (probably within 1000 m).

Indicator Minerals

Several other heavy minerals have interesting distributions within the Lac des Iles study area and shed light on dispersal train dimensions. Their spatial relationships with the Mine Block intrusion may provide clues as to the possible processes involved or related to mineralization. Two heavy minerals, chromite and chrome andradite garnet, occur in samples from the Lac des Iles case study area and are not in any of the samples collected in the other case study areas.

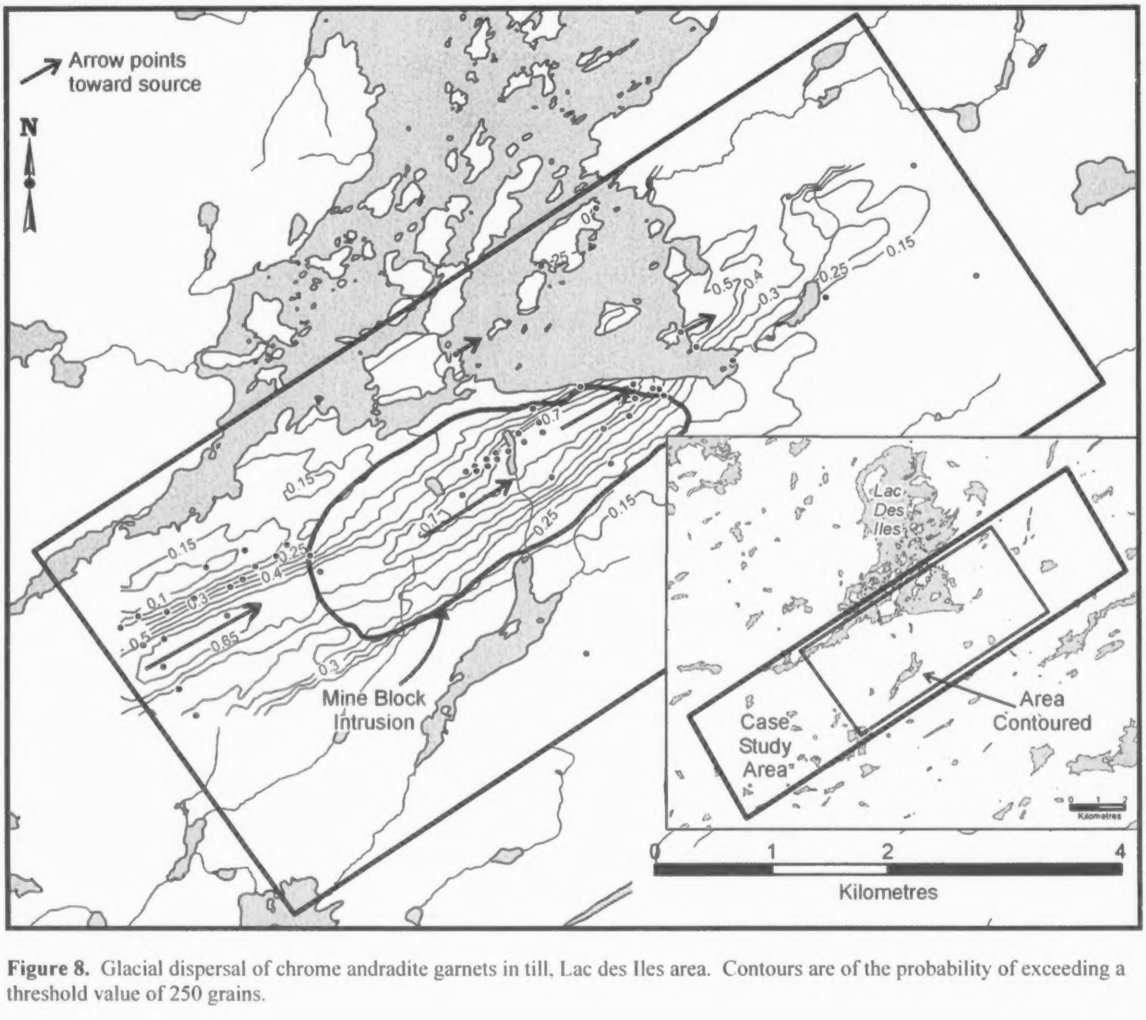

Figure 8. Glacial dispersal of chrome andradite garnets in till, Lac des Iles area. Contours are of the probability of exceeding a threshold value of 250 grains.

One heavy mineral, chrome andradite garnet, has only been recognized in samples from the Lac des Iles study area (Searcy 2001; this study). Grains of this mineral range from 0 to an estimated 7000 grains per sample. They are pale green-white in colour and have a drusy cryptocrystalline habit. Some of the chrome andradite grains and many of the chromite grains "tend to be spotted red with serpentine, suggesting that their source is in ultramafic rocks" (S.A. Averill, Overburden Drilling Management Limited, personal communication, September 10, 2004). "In the most anomalous sample … some of the coarsest (1.0 to 2.0 mm) Cr-andradite grains appear to occur as veinlets …" that "probably formed at relatively low temperature given the serpentine association and the unusual (for garnet) drusy, cryptocrystalline form" (S.A. Averill, Overburden Drilling Management Limited, personal communication, September 10, 2004).

Several sources are indicated by the distribution of Cr-andradite garnets in samples from the Lac des Iles area (Figure 8), however, to date, no chrome andradite garnets have been identified in rock samples. Two independent dispersal trains are directly down ice-flow direction of narrow belts of rocks mapped as mafic suite hornblende gabbro, pyroxene-hornblende gabbro by Stone et al. (2003). The largest or main dispersal train appears to head in rocks mapped as ultramafic pyroxene group (Stone et al. 2003), including olivine websterite, websterite, orthopyroxenite and clinopyroxenite, at the eastern margin of the Mine Block intrusion. This train may be composed of 2, possibly 3 overlapping trains including one that might originate along the western margin of the Mine Block intrusion. In total, the composite train measures about 7 to 8 km in length and varies between 400 and 600 m in width. The individual trains are more likely 1.5 to 4 km in length.

The chrome andradite garnets are commonly skarn minerals formed by metamorphism of carbonate rocks. However, in the Lac des Iles area, they may have formed within a contact metamorphic or metasomatic halo around the Mine Block intrusion where the metamorphic halo intersected rocks containing high-calcium pyroxenes.

Chromite grains were only found in heavy mineral concentrates from the Lac des Iles study area as well. Values range from 0 to estimates of 200 grains per 10 kg sample. Three areas of elevated chromite grains occur and are associated with ultramafic rocks along the northern margin of the Mine Block intrusion and in the Baker zone. Chromite dispersal trains are not as well defined as the chrome andradite garnet trains, however, they are in the order of 500 m to 2 km in length depending on the concentration of chromites; the higher number of grains, the longer the dispersal train.

C-HORIZON TILL SAMPLE GEOCHEMICAL RESULTS

Well-defined dispersal trains with C-horizon till occur within the Lac des Iles study area for several elements. Regional dispersal trains, for elements such as Mg, Cr, Ni and Co associated with the Mine Block intrusion, can be detected for about 4 km beyond its western (down-ice flow) margin. Entire regional dispersal trains range from 5 to 7 km in length and about 1 to 2 km in width.

The geochemical results discussed below are based on fire assay and ICP for PGEs and ICP on the <63 μm fraction for the other trace elements. A summary of the results is presented in Table 5. Results for all the geochemical analyses performed are contained in MRD 154, published separately from this report.

Table 5. Geochemical results for selected elements in C-horizon till samples (–250 mesh).

Study Area		Pd (ppb)	Pt (ppb)	Au (ppb)	Ni (ppm)	Cu (ppm)	Cr (ppm)	Co (ppm)	Zn (ppm)	Mg (%)	Fe (%)
Lac des Iles	(n=72)										
	mean	3.7	3.1	1.7	83.1	53.4	95.1	16.6	33.9	1.2	3.0
	standard deviation	2.2	0.9	1.1	46.4	17.1	64.9	3.7	5.4	0.4	0.4
Tib Lake	(n=31)										
	mean	3.0	2.6	1.8	34.7	57.6	27.3	12.7	37.2	0.6	2.9
	standard deviation	1.4	0.7	3.1	5.3	19.7	3.3	1.9	5.0	0.1	0.3
Cheeseman Lake	(n=27)										
	mean	4.3	2.4	2.4	31.3	128.5	26.6	13.0	31.2	1.5	3.1
	standard deviation	1.8	1.3	1.3	4.8	77.4	3.6	3.1	8.8	0.7	0.6
Circle Lake	(n=26)										
	mean	4.2	5.0	2.2	45.9	119.9	25.9	39.3	39.3	1.2	3.4
	standard deviation	3.2	2.3	1.3	22.0	110.8	5.7	16.0	16.0	1.4	0.8
Tarrison Lakes	(n=2)										
	mean	2.4	2.7	1.6	41.5	107.0	34.0	37.1	37.1	1.1	3.2
	standard deviation	1.0	0.3	0.4	1.9	38.6	1.9	0.9	0.3	0.3	0.2
all samples	(n=158)										
	mean	3.7	3.2	2.1	52.8	72.9	47.2	15.1	35.0	1.1	3.5
	standard deviation	2.2	1.5	1.9	43.5	70.0	62.1	4.4	9.0	0.8	0.5

Platinum Group Elements

Dispersal trains of Pt, Pd and Au are not well defined and tend to be very short, less than 1 km, due to the initial, low concentrations of these elements in C-horizon till samples from the Lac des Iles study area. In addition to the Roby zone (the mine site), elevated Pd values in till occur at the eastern end of the Baker and Creek zones. Two C-horizon till samples (Lac-Soil-2027 and Lac-Soil-2030) collected in the vicinity of the Baker zone, less than 150 m west of Shorty Lake, contained anomalous concentrations of Pd. Sample Lac-Soil-2030 also contained anomalous Pt and sample Lac-Soil-2027 an elevated value. Another sample (Lac-Soil-2054) containing anomalous levels of Pt is located at the far northwestern edge of the case study area. Elevated levels of Pt and Pd also occur in samples collected down-ice flow direction of the Roby zone, however, their source may be to the west of the Roby zone. Short dispersal trains of Pt originate northeast of Shorty Lake, northeast of the Creek zone and the Roby zone. Larger and better defined dispersal trains are associated with PGE indicator elements such as Ni, Mg, Cr and Co. In general, till samples contain higher amounts of Cu south of the Mine Block intrusion except near the Roby and Twilight zones.

Gold showed anomalous values in 2 samples: Lac-Soil-2031 near the anomalous Pt and Pd samples at the Baker zone and Crk-Soil-2002 collected about 50 m northeast of the margin of the varitextured gabbro of the Mine Block intrusion.

Associated Elements

Well-defined dispersal trains for several trace elements that are commonly associated with Pt and Pd occur in the Lac des Iles case study area. The distributions of Ni, Cr, Mg and, to a lesser extent, Co in C-horizon till samples are similar, whereas distribution of Cu is not. Contouring of trace element concentration distributions using inverse distance weighting techniques produces regional dispersal trains of about 6 to 7 km in length and 1 to 2 km in width for Ni, Cr, Mg and Co, oriented parallel to the latest ice flow direction of about 240 to 245°. There are indications that the dispersal train is composite, composed of 2 or 3 trains that begin along the eastern margin and in the vicinity of the western margin of the Mine Block intrusion. Using an automated contouring method (kriging) that accounts for the anisotropy of glacially dispersed debris, 3 distinct dispersal trains for Cr (Figure 9) and Mg, 3 to 5 km in length and 300 to 500 m in width can be delineated. For Ni, 5 smaller trains are indicated (Figure 10), 3 of which correspond to the trains of Cr and Mg. The largest of the trains of Ni, Cr and Mg correspond with the major train of chrome andradite garnet distribution (Figure 11). The westernmost train appears to be emanating from the Roby zone (the mine site). The source of the other 2 trains has yet to be investigated.

The patterns of the associated trace elements, such as Ni, Cr and Mg, indicate that although the rocks of the Mine Block intrusion and surrounding areas are very similar in appearance, there are significant variations in trace element chemistry. In general, the associated trace elements form larger dispersal trains than PGEs due to their greater initial abundance making them larger targets for mineral exploration surveys using C-horizon till samples.

Copper and nickel occur together in high concentrations in C-horizon till samples immediately down ice of the Roby zone and, to a lesser amount, in a narrow band extending from the northern part of the Baker zone up-ice flow direction (approximately north-eastward) to Southeast Angle Bay. Copper, however, is high in till samples overlying the southern part of the Mine Block intrusion and to the south and east of it. Samples with anomalous Cu concentrations include Crk-Soil-2002, Crk-Soil-2016, Lac-Soil-2003 and Lac-Soil-2052 (*see* MRD 154).

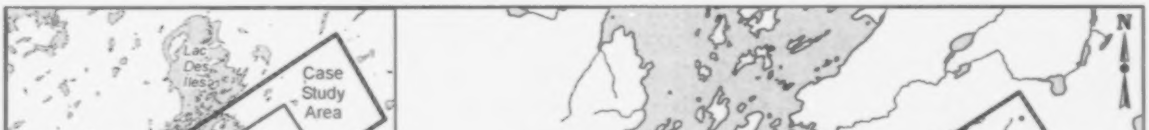

Figure 9. Glacial dispersal of chromium in C-horizon till samples (–250 mesh), Lac des Iles area. Contours are of the probability of exceeding a threshold value of 115 ppm.

Samples with anomalous values of Cr (Crk-Soil-2010, Crk-Soil-2012), Mg (Crk-Soil-2012) and Co (Lac-Soil-2022) occur along the northern and northeastern rim of the Mine Block intrusion. Several other samples with elevated concentrations of Ni, Cr, Mg, and Co occur in same general areas.

Till: Soil Profile Geochemistry

Following deglaciation, the materials making up the land surface were exposed to weathering and soil forming processes. The parent material (C-horizon) of the soil begins to alter physically and chemically in response to these processes and other soil horizons form. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter), was also sampled during this project.

In all of the case study areas that have soils developed entirely in till, there is generally a decline in concentrations of Pt, Pd, Ni, Cu and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7), of the 5 basic geochemical profile types proposed by Klassen (2003). The majority of sites in the Lac des Iles study area, however, have the Type 2, "accumulation (surface)", profile, that is, net downward increase with humus maxima (Klassen 2003), for Pd, Pt, Cu and to a lesser extent Ni (*see* Figure 7).

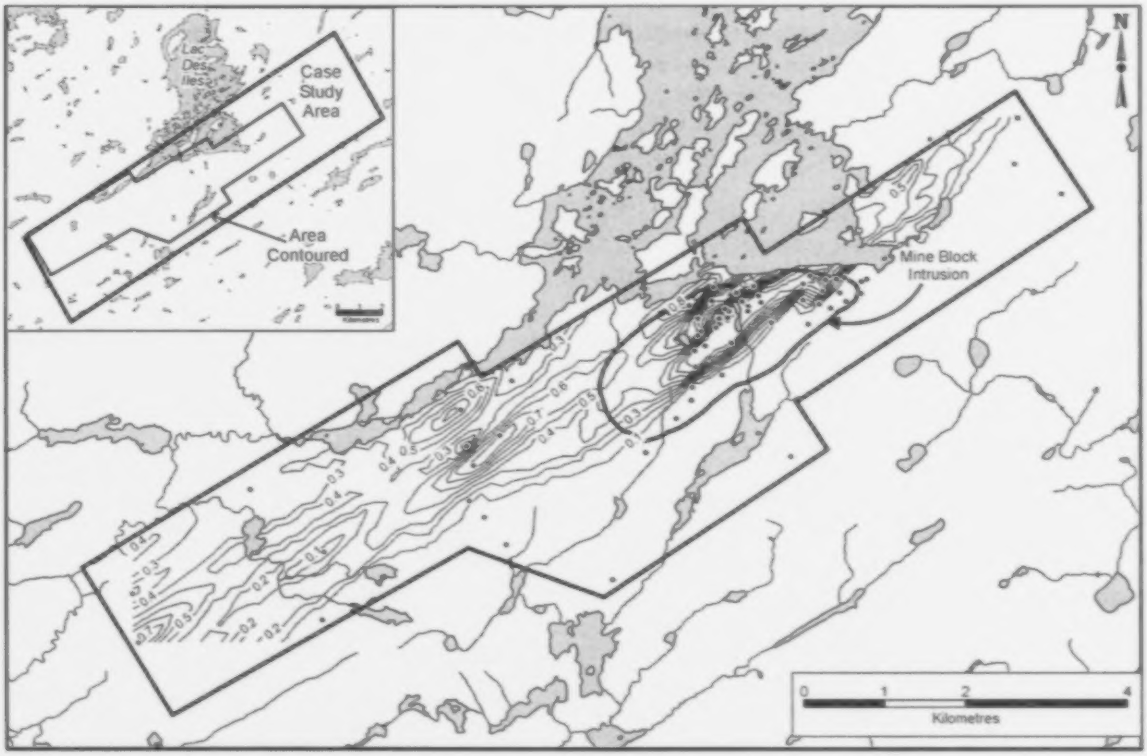

Figure 10. Glacial dispersal of nickel in C-horizon till samples (–250 mesh), Lac des Iles area. Contours are of the probability of exceeding a threshold value of 100 ppm.

There are major disconnects between the mineral soil layers and the humus at Lac des Iles. Concentrations of these elements can be 10 to 100 times larger in humus samples than the corresponding B- and C-horizon samples. Differences in concentrations between humus and C-horizon samples collected at the same sites generally decrease eastward from the mine workings, waste rock and tailings areas (Figure 12). This relationship is believed to be the result of airborne contamination of humus samples by dust from these disturbed areas (anthropogenic input, Photo 5). Airborne contamination of the humus at this case study site has adversely affected the ability to determine the effectiveness of humus sampling for mineral exploration. The airborne contamination likely influences surface and ground water and organic bog samples as well.

Zinc commonly follows the Type 2, "accumulation (surface)", geochemical profile type in soil profiles developed in till from all case study areas (Klassen 2003: *see* Figure 7). For this element, however, biological processes are the preferred methods of enrichment in humus samples.

PLATINUM GROUP ELEMENTS

The general trend in Pd concentrations is one of decreasing concentrations up through the mineral soil (C-horizon to B-horizon). There is a major disconnect between concentrations in the mineral soil and in humus at the Lac des Iles site. The humus samples are extremely elevated in Pd, most likely the result of airborne contribution of dust from the active mine site and haul roads (*see* Figure 12). Only 3 sites have a geochemical profile with decreasing Pd content up through the entire soil profile (Type 1: Klassen 2003)

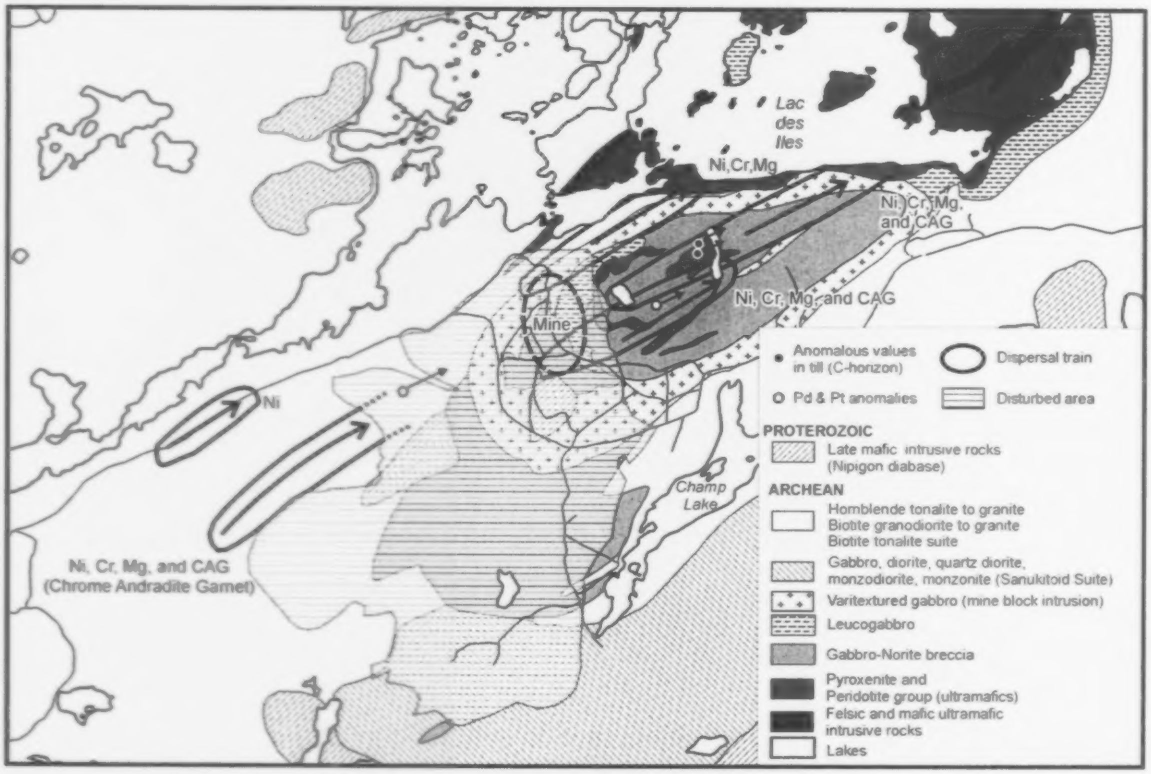
Lac des Iles
Ni,Cr,Mg
Ni, Cr, Mg, and CAG
Ni, Cr, Mg, and CAG
Mine
Ni
Champ Lake
Ni, Cr, Mg, and CAG (Chrome Andradite Garnet)
Anomalous values in till (C-horizon)
Dispersal train
Pd & Pt anomalies
Disturbed area
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Varitextured gabbro (mine block intrusion)
Leucogabbro
Gabbro-Norite breccia
Pyroxenite and Peridotite group (ultramafics)
Felsic and mafic ultramafic intrusive rocks
Lakes

Figure 11. Multiple element and mineral dispersal trains developed in till with vectors to source areas, Lac des Iles area.

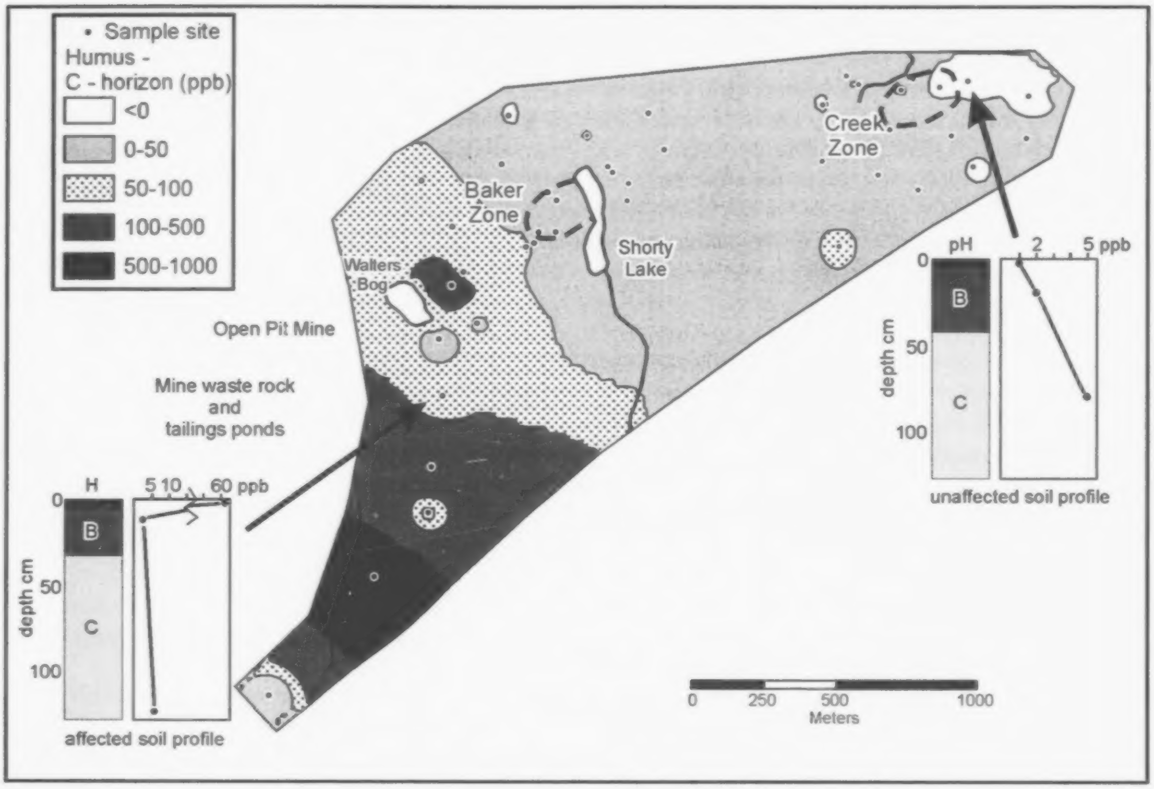

Figure 12. Concentrations (ppb) of Pd in humus minus concentrations of Pd in C-horizon till samples, Lac des Iles area. Figure also shows location of Shorty Lake, the Baker zone and Creek zone relative to the mine.

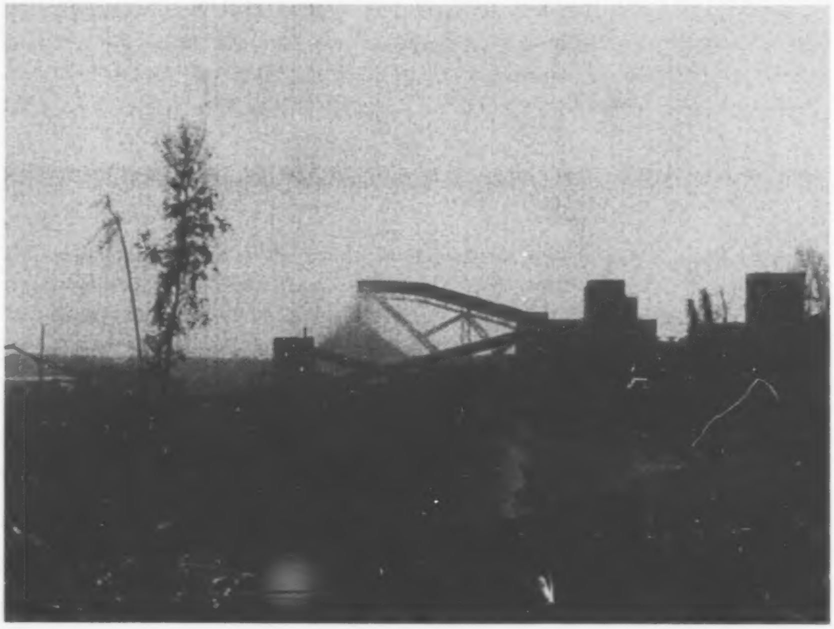

Photo 5. Airborne dust from crushing operations at Lac des Iles Mine.

similar to those present in the other case study areas. These sites are distant to workings and haul roads, in forested areas or on high ground. Palladium appears to be moving out of the soil system downslope into surface and shallow groundwater. The addition and distribution of Pd containing dust from the active mine area and haul roads may influence the geochemical results from other sample media.

The soil profile geochemistry of Pt is similar to that of Pd. In general, overall concentrations are less and the mobility or degree of decrease in concentration up the soil profile is less than Pd. At a few sites, Pt concentrations are greater in the B-horizon than C-horizon. These sites are located at the base of steep bedrock-controlled slopes where downslope movement of Pt in surface and shallow ground water may have added to the Pt concentration in the B-horizon. It appears that the concentration of Pt is naturally less in humus than B-horizon samples, but, in the Lac des Iles area, there are many exceptions, probably the result of airborne contamination.

The Au content in soil samples, like Pd and Pt, decreases upward through the mineral soil horizons and is enriched in the humus. The enrichment in humus samples may be in part the result of airborne dust contamination.

ASSOCIATED ELEMENTS

Overall Cu content decreases up through the mineral soil developed in till at the Lac des Iles study area. An increase in Cu concentration occurs in humus samples collected in close proximity to open pit mine, tailings and haul roads, similar to Pd and Pt, however, the effect and extent of measurable airborne contamination is not as great due to the higher initial contents of naturally occurring Cu. Copper behaves similar to Pd, being very mobile in soils at Lac des Iles. It is not uncommon to observe a 50% reduction in Cu content from C-horizon to B-horizon samples. At approximately 10% of the sites studied, the concentration of Cu in B-horizon samples exceeded that in C-horizon samples. This may be a function of the original distribution of Cu within the till itself prior to weathering.

There is a general trend for the concentration of Ni to decrease up through the soil profiles developed in till. There is not as much removal of Ni as occurs with Cu in the B-horizon, that is, the geochemical gradient or mobility is not as great for Ni as Cu in soil developed under the climatic conditions in the Lac des Iles study area. Nickel concentrations in B-horizon samples are higher than the underlying C-horizon material in about 10% of the profile sites studied. Half of these sites are down-ice flow from high Ni concentrations in C-horizon samples and possibly reflect down-ice dispersal of Ni, whereas, the Ni content in the C-horizon samples at these sites may have been diluted by local incorporation. Nickel content in humus is lower than in B-horizon samples, except at 6 sites that are located in close proximity to the tailing ponds, mine workings and haul roads of the Lac des Iles Mine. The effect and extent of measurable airborne contamination is not as great due to the higher initial naturally occurring content of Ni in the area.

Chromium content in soils developed in till have a geochemical profile with decreasing Cr content up through the entire soil profile (Type 1: Klassen 2003). Less than 2% of the profiles studied have Cr enriched in the humus layer. For Cr, 40% of the profiles showed variations between B- and C-horizons less than the error of laboratory measurement.

Cobalt profile results display very little change between the various mineral soil horizons, but most indicated depletion or low values in humus samples. For Zn, most variations observed between horizons are less than the potential error of analysis, however, there appears to be a general decrease in Zn concentration from C-horizon to B-horizon samples and an increase in the Zn concentration in humus samples.

In summary, the behaviour of Ni in the soil environment is similar to that of Pt and can be used as a proxy. The behaviour of Cu in the soil environment is similar to that of Pd with respect to relative mobility. Geologically, Pt and Ni and Pd and Cu are often associated.

B-HORIZON TILL SAMPLE RESULTS

As discussed above, most of the elements of interest occur in greater abundance in C-horizon samples than in B-horizon samples. This might lead one to the conclusion that sampling the C-horizon might be the best method for mineral exploration of PGEs. However, for several trace elements the results of B-horizon samples are useful. For Ni, Mg and Cr, B-horizon sample results target only the heads of dispersal trains defined by C-horizon samples. The B-horizon targets are much smaller, however, there is some evidence of downslope movement of elements and blurring of the target area (Figure 13).

RESULTS OF HUMUS OVERLYING MINERAL SOIL DEVELOPED IN TILL

As discussed above, the humus samples appear to be contaminated by airborne dust derived from mining operations. This is best illustrated with Pd and Pt, elements that have initially low natural concentrations (*see* Figure 12). Whereas glacial dispersal (C-horizon results) has created geochemical gradients toward the southwest, the geochemical gradients in the humus samples are generally eastward. By subtracting the concentrations of the various elements of interest in humus from the underlying C-horizon concentrations the affected areas of the airborne contamination can be seen (*see* Figure 12).

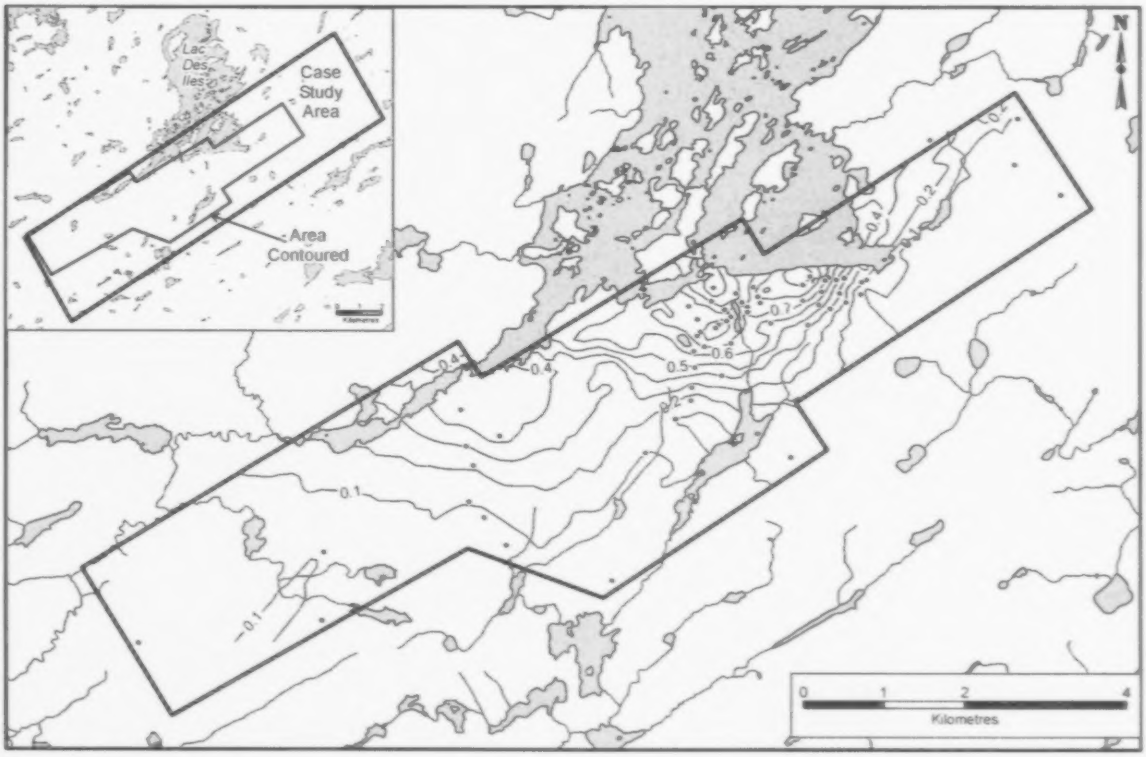

Figure 13. Hydromorphic dispersal of Ni in B-horizon till sample (–250 mesh), Lac des Iles area. Contours are of the probability of exceeding a threshold value of 63 ppm.

Lake Sediments

Due to the development of the Lac des Iles Mine site, most lakes within the drainage catchment encompassing the Roby zone could not be sampled. Therefore, evidence of the PGE mineralization in the Lac des Iles Mine area is restricted to 3 lakes, namely Shorty Lake, Camp Lake and Walters Bog. All 3 have within their drainage catchments the Baker zone Cu-Ni-PGE mineralization. Walters Bog lies in an area of poor natural drainage, approximately 600 m west of the Baker zone and 500 m northeast of another Ni-PGE occurrence known as the Twilight zone. It has likely been the recipient of a mixed signal, dominated by the general geochemical signal of the Mine Block intrusion, with some influence from the Baker zone and its down-ice geochemical plume developed in till. Lake sediment samples (both surface, shallow sediment and deep sediment) were obtained from Walters Bog during this study. The results for Pd, Pt and Au from deep sediment (>20 cm) were 5.4, 0.8 and 3.5 ppb, respectively. These levels are roughly half as high as the results obtained from Shorty Lake deep sediment (13.6 ppb Pd, 3.6 ppb Pt and 5 ppb Au). This drop in geochemical intensity with distance might serve as a general guideline for explorationists to understand how the magnitude of PGE lake sediment anomalies relate to distance from mineralization. The shallow (surface) sediment from Walters Bog returned much higher levels of Pd (42.8 ppb), Cr (52.9 ppm) and Ni (72.3 ppm) than the deep sediment (5.4 ppb Pd, 12.9 ppm Cr and 26.7 ppm Ni). This indicates an anthropogenic input into Walters Bog; probably the result of a combination of surface runoff and airborne dust from the nearby mine roads and dust from the rock crushing operations at the nearby mill.

The Baker zone is an elevated and exposed source of Cu-Ni-PGE mineralization and, therefore, appears to be an excellent test area to study the hydromorphic dispersion of metals from a point source. The lake sediment sample from the adjacent Shorty Lake returned anomalous Cr, Ni, Pd and Pt, but only elevated Cu. This result has previously been attributed to the high grade Baker zone, which lies approximately 100 m upslope (Dyer and Russell 2002; Hattori and Cameron 2004). Shorty Lake was originally not sampled during the field work for the regional lake sediment survey by the OGS (Dyer and Russell 2002). This was rectified in June 2002, when 6 lake sediment samples were obtained. Four of the samples were provided to E.M. Cameron for his Ontario Mineral Exploration Technology (OMET) project on Pd exploration (Cameron and Hattori 2005). Two samples (shallow and deep sediment) were kept by the OGS; the results of the deep sediment were published in the regional Lac des Iles–Black Sturgeon River lake sediment survey (Dyer and Russell 2002). Comparison of Shorty Lake shallow and deep sediment shows enrichment of Au (21 versus 5 ppb) and Pd (15.7 versus 13.6 ppb) in the shallow sediments, but no significant difference in the levels of Co, Cr, Cu and Ni (in fact, the shallow sediment returned lower levels of all these metals). The difference in gold levels may be due to the nugget effect; the difference in Pd levels is not significant considering that the estimated precision of the Pd analysis is ±5 ppb. The 4 samples (2 shallow and 2 deep sediment) analyzed for the Pd OMET project returned essentially the same results (Cameron and Hattori 2005). These results seem to indicate that there has been little effect of airborne dust contamination on Shorty lake sediment.

Lithogeochemistry

Shoreline traversing of Shorty Lake during this study resulted in the discovery of mineralized bedrock on the northwest shore within 6 m of the lake. A grab sample of gabbro from this outcrop, containing approximately 2% sulphides, returned 979 ppb Pd, 139 ppb Pt, 313 ppb Au, 2740 ppm Ni and 3960 ppm Cu (Figure 14). This occurrence demonstrates that mineralized bedrock is much closer to Shorty Lake than previously thought and has likely contributed a geochemical signal of significance to the lake sediment and nearby humus and surface peat deposits. Three other samples of gabbro were collected around Shorty Lake; of note is a value of 703 ppm Cr from a sample along the northeast shore (site LAC-RK-3), which correlates well with the anomalous Cr in the lake sediment and anomalous Cr in groundwater (discussed below).

No bedrock sampling was undertaken on the stripped Baker zone, however, lithogeochemical data were provided by North American Palladium Limited (J. Rickard, North American Palladium Ltd., written communication, 2004). Results for Pd, Ni and Cu from 34 rock samples from the Baker zone averaged 1.1, 1043 and 1467 ppm, respectively. The average Ni to Cu ratio for these 34 samples was 3.8:1.

Hydrogeochemistry

The focus of the water sampling in this study area was the Baker zone, in order to characterize the dispersion of metals away from a strong point source. Sampling was extended out to "background" areas to put the levels near the Baker zone into the proper context. Therefore, samples were collected around

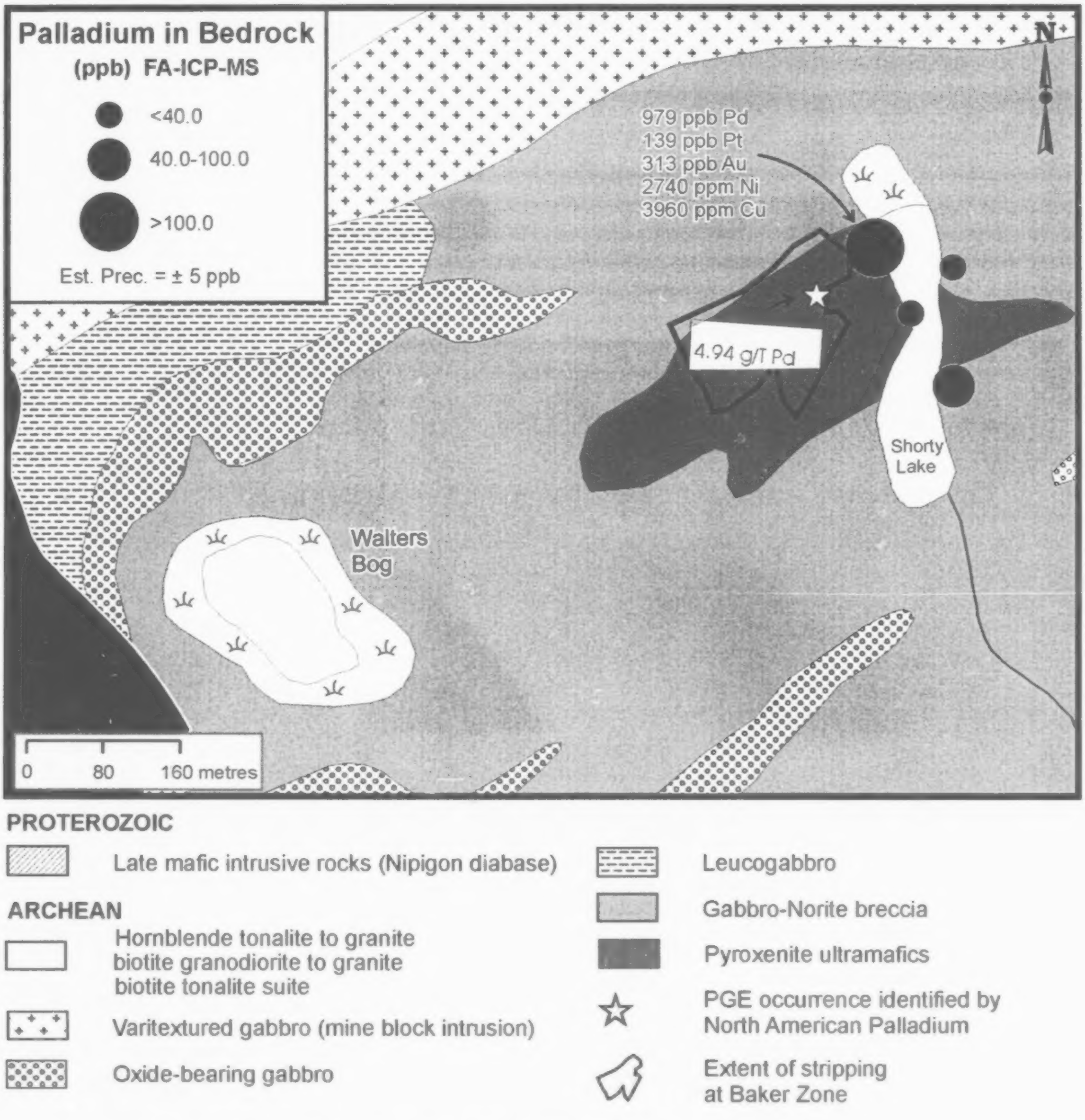

Figure 14. Palladium in bedrock, Shorty Lake area, Lac des Iles area.

Walters Bog and to the southwest beyond the mine development. The samples (peat and bog water) collected in the southwest beyond the mine waste and tailings areas also served to determine if these media could produce a metals response due to the down-ice geochemical plume related to the Mine Block intrusion and associated mineralization.

Sampled water pH within the study area are neutral to slightly acidic. The pH of bog waters (obtained in surface sumps or at ~1 m depth by piezometer) averaged approximately 6.6, likely reflecting the presence of natural organic acids. Overall, the neutral to slightly acidic pH conditions within the Lac des Iles study area are conducive for hydromorphic transport of metals.

Electrical conductivities of almost all waters collected within the Lac des Iles study area are relatively high compared to the levels observed at the other case study areas, except for Tarrison Lakes. Walters Bog and the Shorty Lake–Camp Lake drainage system (draining to the southwest) are anomalously high compared to the regional data which cover the area (Dyer and Russell 2002). This indicates that higher element loading (total dissolved solids) is being contributed to this drainage system(s). In the absence of baseline data, it cannot be ascertained unequivocally whether this is the result of anthropogenic input or is natural. However, a possible cause (or at least a contributor) to these conductivity levels, and a variable that may have effected the surficial geochemistry around the Baker zone, in particular downslope to the north, east and south of the high-grade showing, is the tremendous amount of soil (till) that has been stripped (washed) off the top of the hill, presumably by high-powered water pumps. Significant gullies or gulches are present, notably at the northeast end of the Baker zone leading towards the swamp at the north end of Shorty Lake. In fact, a fence is in place to keep eroded material from reaching Shorty Lake. It is possible this disturbance has attenuated the geochemical signal (both clastic and hydromorphic dispersion) determined in the waters and surface media that lie between the north end of Shorty Lake (including the bog) and the Baker zone topographic high. This significant disturbance likely renders the Baker zone as less of an ideal case study site than previously thought, especially for use as an analogy to assist in exploration for new (undisturbed) mineralization.

BOG WATER

The results for Ni, Cu and Cr in bog waters from dug sumps around the Baker zone are significantly higher than those obtained from background sites southwest of the mine site. For example, Ni levels encircling the Baker zone were all over 12 ppb, with a peak of 26 ppb; background sites returned <4 ppb Ni (Figure 15). Copper and Cr returned similar patterns.

The precious metals (Au, Pd and Pt) returned a weak but similar pattern by having higher values adjacent to the Baker zone (but only at sites to the north of the stripped area) and low values (near or at detection limit) at the background sites. Exceptions to this were at site LAC-BOG-30, which returned 24 ppt Pd and 89 ppt Pt from sump water. This sample site is approximately 250 m southwest of the raised mine development built on a base of waste rock. The highest water conductivity of the area, 1022 µS/cm, was also obtained at this location. It is most likely that this site is being affected by drainage from the mine workings. The other exception was at site LAC-SS-2, which is located well away from the Baker zone and drains an area off the Mine Block intrusion. Water here was obtained by a dug sump due to the ephemeral nature of the drainage. An analysis of 4 ppt Pd obtained here was higher than similar analyses near the Baker zone. The sample site was 35 m upstream from the mine road, therefore, it is unlikely that direct contamination from the roadway influenced this result, however, airborne dust contamination from either the road or the more distant milling operation cannot be ruled out.

At the bog at the north end of Shorty Lake, the water sump sample site closest to the Baker zone (and also closest to Shorty Lake) returned only background levels of Au, Pd and Pt. Dilution due to proximity to the lake is the likely reason for these low values; higher levels were obtained in the sump waters farther to the north away from the lake.

Conductivity results from waters obtained by piezometers show high levels (>100 µS/cm) spatially associated with the Baker zone. The background sites had conductivities of <75 µS/cm. Detailed piezometer installations at the north end of Shorty Lake indicate higher conductivities on the east side compared to the west. All piezometers were driven to approximately the same depth (~1 m). However,

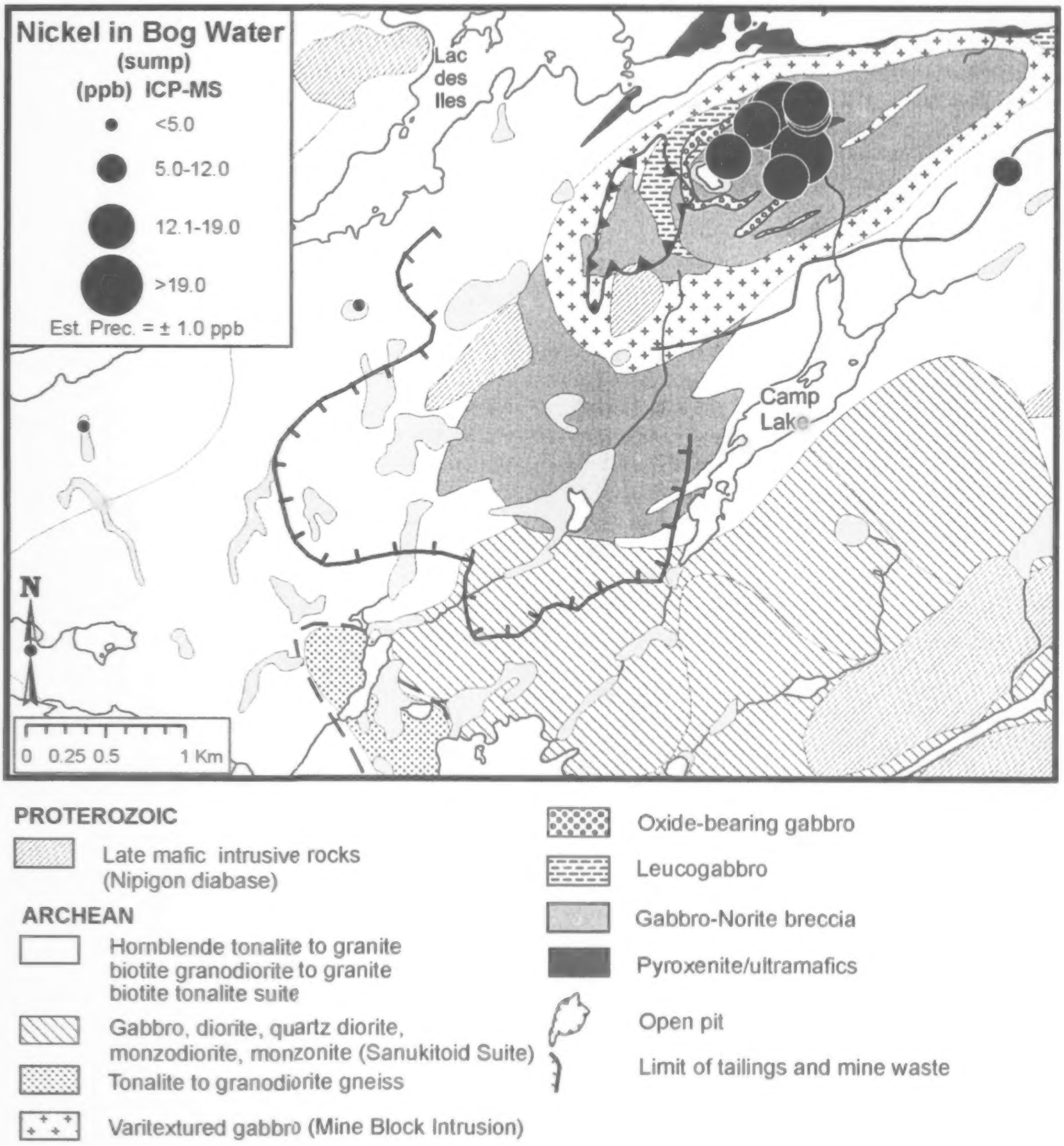
Nickel in Bog Water
(sump)
(ppb) ICP-MS
<5.0
5.0-12.0
12.1-19.0
>19.0
Est. Prec. = ± 1.0 ppb
Lac des Iles
Camp Lake
N
0 0.25 0.5 1 Km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Tonalite to granodiorite gneiss
Varitextured gabbro (Mine Block Intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite/ultramafics
Open pit
Limit of tailings and mine waste

Figure 15. Nickel in bog water (dug sumps), Lac des Iles area.

it was observed that the peat obtained from the west side contained more water. Slightly lower pH levels (typically <7) from the west side compared to the east side (consistently >7) is not likely due to dilution from Shorty Lake, which has a pH of 7.3. It is possible that a higher flux of metals from the Baker zone area has caused more acidity (akin to acid mine drainage) on the western side of the bog.

The results for Ni, Cu and Cr from piezometer waters obtained around the Baker zone are distinctly higher than the background sites at Walters Bog and southwest of the mine development. Nickel levels show the best contrast; levels in the vicinity of the Baker zone are >10 ppb, whereas background levels are <5 ppb Ni (Figure 16). In addition, all 3 elements show evidence of a higher geochemical flux

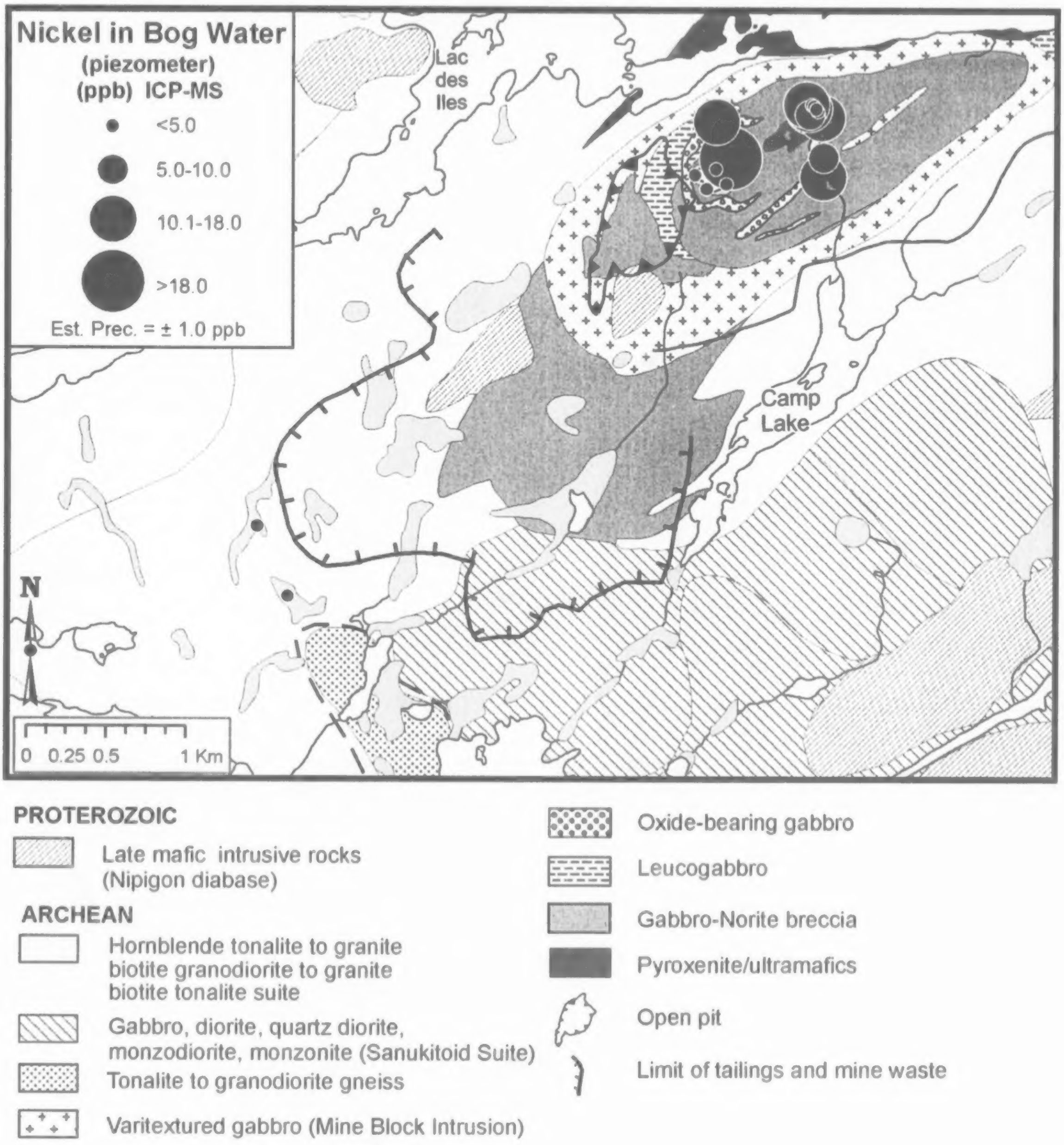
Nickel in Bog Water
(piezometer)
(ppb) ICP-MS
<5.0
5.0-10.0
10.1-18.0
>18.0
Est. Prec. = ± 1.0 ppb
Lac des Iles
Camp Lake
N
0 0.25 0.5 1 Km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Tonalite to granodiorite gneiss
Varitextured gabbro (Mine Block Intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite/ultramafics
Open pit
Limit of tailings and mine waste

Figure 16. Nickel in bog water (piezometer), Lac des Iles area.

coming from the Baker zone (west piezometers) as opposed to the east side of the bog at the north end of Shorty Lake (Figure 17). Interestingly, the highest Cr value of 9.5 ppb at the northeast side of Shorty Lake is coincident (within ~20 m) of the Cr anomalous bedrock sample (LAC-RK-3).

The precious metals (Au, Pd and Pt) returned a relatively weak response, but a pattern of higher levels spatially associated with the Baker zone and Mine Block intrusion was still evident. Five of 6 Au results above detection limit and 4 of 5 Pd results above detection limit are located on the Mine Block intrusion, mostly related to the stripped Baker zone. The top 3 Pt results also came from samples collected around the Baker zone. The highest Pt value came from the sample site closest to the high-grade Baker zone. However, the 2 highest Pd values came from the sample sites on the west side of Walters Bog. This may be evidence of geochemical flux (contamination) originating from the mine workings.

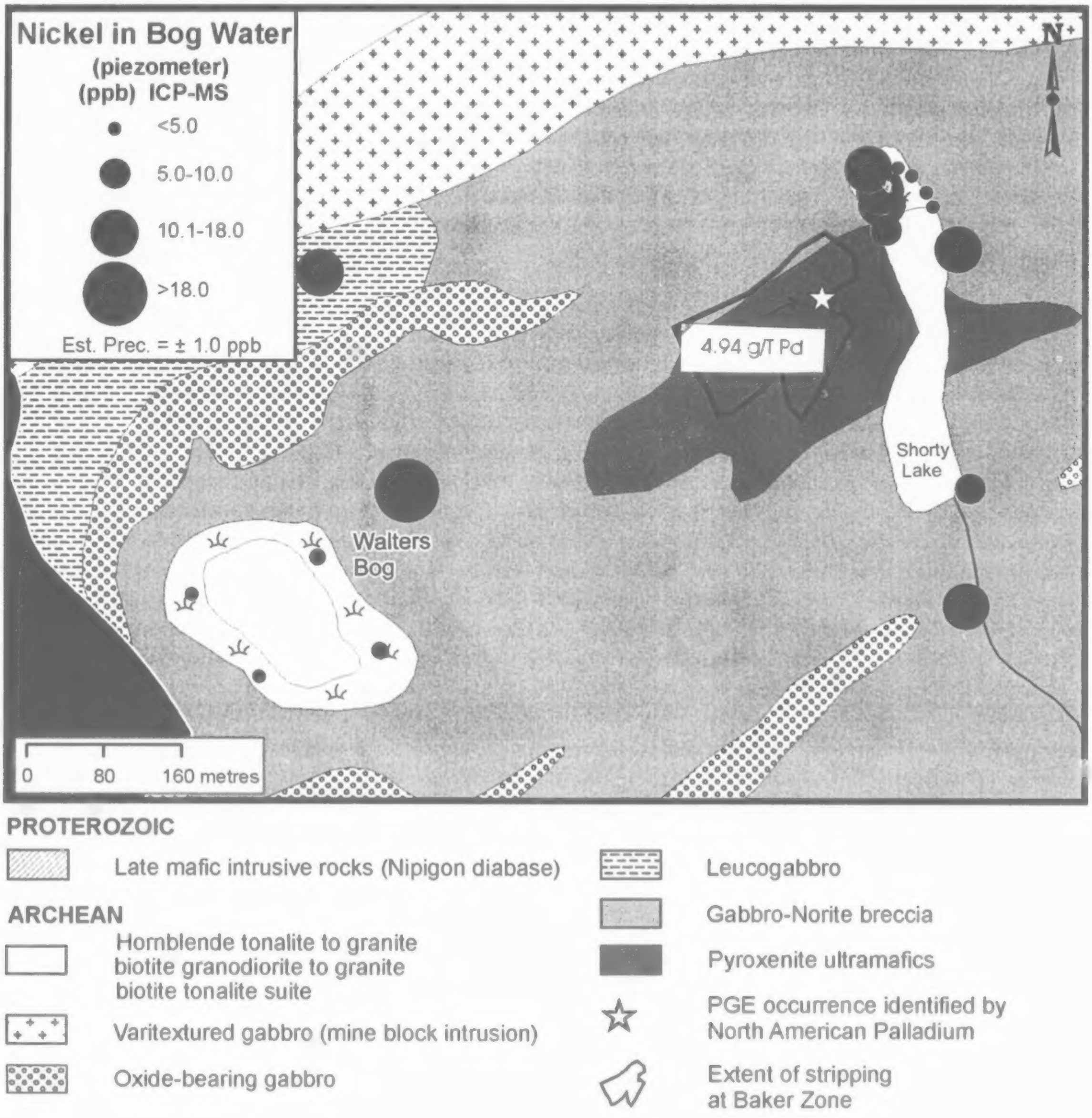

Figure 17. Nickel in bog water (piezometer), Baker zone, Lac des Iles area.

Table 6. Comparison of waters collected from swamps, Lac des Iles study area.

	Co (ppb)	Cr (ppb)	Cu (ppb)	Ni (ppb)	Sn (ppb)	Ti (ppb)	Pd (ppt)	Pt (ppt)	Au (ppt)	pH	Conductivity (µS/cm)
Bog water (sump) (n=12)											
mean	**3.13**	**7.2**	**5.2**	**14.1**	<0.1	**13.9**	**3.2**	**7.7**	**0.5**	6.5	196
median	**2.42**	**7.2**	**5.2**	**14.6**	<0.1	**13.1**	**0.8**	**0.3**	**0.2**	6.6	122
Bog water (piezometer) (n=19)											
mean	0.82	3.1	4.6	7.8	**0.6**	9.8	0.7	0.3	0.2	**6.6**	180
median	0.66	2.3	2.1	4.7	**0.5**	7.8	0.5	0.2	0.1	**6.9**	153

A statistical comparison of the geochemical results between bog waters collected by sump and those collected slightly deeper (~1 m) by piezometer is contained in Table 6.

Higher levels of base and precious metals in the surface waters compared to deeper waters may be further evidence of airborne contamination due to the mining and milling operations. However, sump and piezometer bog water data from another case study completed by the OGS over the Victoria Creek gold deposit near Kirkland Lake (with no apparent nearby source of contamination) display a similar, but weaker relationship for a number of elements including Ni and Cu (S.M. Hamilton, OGS, unpublished data, 2004). However, that study also demonstrated that elements such as Al, Ba, Ce, Co, Cr, Fe, Mn and Ti are clearly higher in deeper water, which is opposite to the results of this study. Therefore, evidence suggests that the surface landscape near the Lac des Iles area is being effected by an anthropogenic input in addition to a natural signature from geology.

GROUNDWATER

Seven samples of groundwater outside of bogs were collected near the Baker zone. Three of the samples came from 2 diamond-drill hole located on the stripped Baker zone clearing. Standing water was purged from the boreholes using a Teflon™ foot valve and polypropylene hose. The water was allowed to recover over several days; then, final purging of approximately 25 L was done prior to sampling the water at a depth of approximately 22 m downhole. Two spring samples were obtained on the east side of the Baker zone topographic high, where water flowing towards Shorty Lake emerged from overburden. Finally, 2 groundwater samples were obtained by piezometers placed into dry (ephemeral) stream drainages north of the Baker zone, that drain towards the bog at the north end of Shorty Lake.

Conductivity and pH of the groundwaters were slightly higher than for surface waters; average pH level was 7.1 compared to 6.5 for surface bog waters and 6.7 for stream waters. Levels of Cu and Ni were significantly higher in the groundwater samples than all other types of waters. The average Cr level was only slightly higher than that obtained from surface bog waters. Each of these elements has a slightly different pattern. Of the 3, Ni has the broadest geochemical footprint and, therefore, seems to have dispersed farther in groundwater than the other metals. The highest Ni value of 62 ppb came from the diamond-drill hole at the eastern end of the Baker zone, which was targeted on high-grade surface mineralization. The second highest value came from a sample downslope from this high-grade zone towards Shorty Lake. Three other samples of groundwater from sites downslope of the Baker zone returned levels greater than 15 ppb. Anomalous Cu levels were returned only from the samples collected from the 2 diamond-drill holes, with a high value of 52 ppb Cu obtained from the easternmost drill hole, targeted on the highest grade part of the Baker zone. The highest Cr numbers were returned from the groundwater seeps on the slope leading to Shorty Lake. This would seem to indicate that the source of the Cr is more likely related to the overburden than the *in situ* bedrock mineralization. The levels for the precious metals in groundwater are, on average, over twice as high as those for the bog water samples.

However, the highest values occur in the waters from the 2 diamond-drill holes, where water is in direct contact with mineralized bedrock. Away from the drill holes, levels drop off rapidly downslope away from mineralization. Figure 18 shows the levels of Pd in groundwater around the Baker zone.

STREAM WATERS

The pH of stream waters in the Lac des Iles case study area averages 6.7 and conductivity averages 162 µS/cm. This level of conductivity is approximately 2 to 3 times greater than the average of all the other study areas. This would seem to indicate that loading into the streams is much more significant than

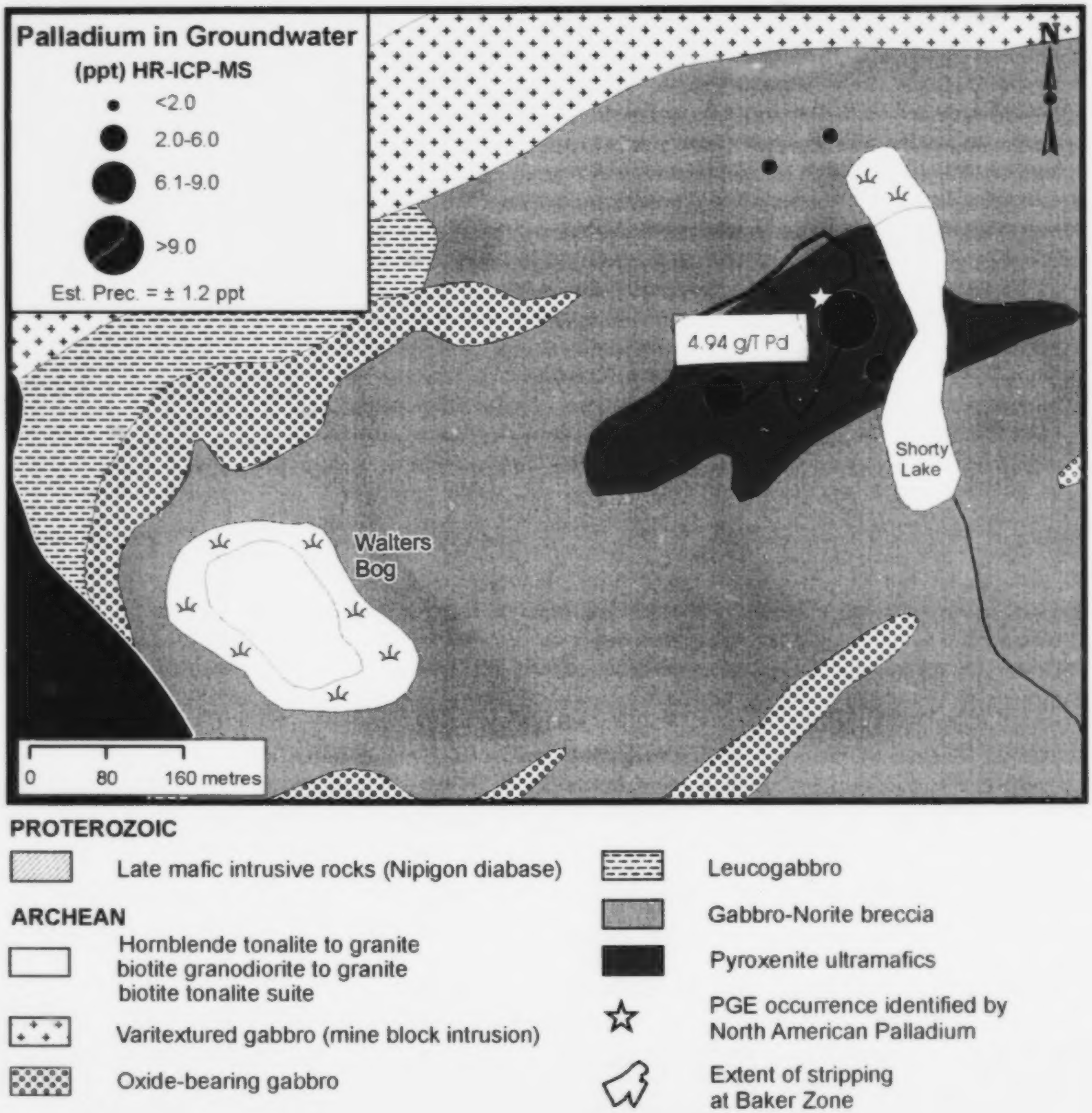
Palladium in Groundwater
(ppt) HR-ICP-MS
<2.0
2.0-6.0
6.1-9.0
>9.0
Est. Prec. = ± 1.2 ppt
N
4.94 g/T Pd
Shorty Lake
Walters Bog
0
80
160 metres
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Varitextured gabbro (mine block intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite ultramafics
PGE occurrence identified by North American Palladium
Extent of stripping at Baker Zone

Figure 18. Palladium in groundwater, Baker zone, Lac des Iles area.

the other case study areas. The 2 highest conductivities are likely due to effects of the mine as the sample sites are located downstream of the main mine road. Three samples south of Shorty Lake have conductivities greater than 100 μS/cm. This contrasts with a level of only 62 μS/cm from a creek east of Camp Lake that drains over tonalite. Of the metals Ni, Cu and Cr, only Cr shows a response that may be related to a source within the Shorty Lake drainage catchment. Two samples collected from the creek draining Shorty Lake have the highest levels of Cr in stream water, which decreases downstream to Camp Lake. The other stream water samples located on the Mine Block intrusion have a higher level of Cr than the background water sample from the area underlain by tonalite. The level of Cu in the creek draining Shorty Lake is significantly lower than the level found in Shorty Lake water itself. However, below the mine road, the Cu level increases significantly; this is likely due to contamination from the roadway. All of the other creeks have a similar level of Cu including the sample from the creek which drains over the tonalite. The nickel pattern is similar to Cu, except for the sample from the area underlain by tonalite, which has a very low Ni response. The stream water data, with the exception of Cr, more clearly reflect the chemistry of the Mine Block intrusion or roadway contamination, rather than Baker zone mineralization.

Very low levels of the precious metals are present in the stream water draining Shorty Lake. The highest levels again occur downstream from the mine road, which are most likely due to contamination. The only elevated response due to geology may be from a small creek to the south of Shorty Lake, which drains eastward into the creek that drains Shorty Lake. Almost 9 ppt Pd and 2.8 ppt Pt were determined in stream water from this location. This corresponds with anomalous levels of PGEs in stream sediment at this location (discussed below).

Peat

The levels of base metals (Cu, Ni, Cr) in organic peat are significantly higher in the vicinity of the Baker zone than at Walters Bog or the samples obtained southwest of the mine site. For example, outside of the influence of the Baker zone, the level of Ni is typically less than 30 ppm, whereas in the vicinity of the Baker zone, the average Ni level is more than 90 ppm and reaches as high as 178 ppm. Nickel and Cr (Figure 19) show the best response in terms of contrast and areal extent of anomalous values compared to samples obtained in background areas. All 3 elements show a pattern of higher levels on the west side of the bog at the north end of Shorty Lake. This would seem to indicate a higher geochemical flux coming from the Baker zone. A very high Cr level was obtained in a sample from the northeastern side of Shorty Lake. This is coincident with anomalous Cr in rock and in water (discussed previously).

Gold in peat was determined by 3 methods (ashed-ICP, fire assay, INAA). All of the results show a general higher background in the vicinity of the Baker zone with several spot highs at the west side of the bog at the north end of Shorty Lake and at 2 sample sites south of the Baker zone. Other than the general pattern of higher levels near the Baker zone, there is very little corroboration of the spot highs between the 3 methods. This is likely, in large part, a reflection of the nugget effect of Au.

The Pd in peat by fire assay results (Figure 20) clearly shows a higher background (Pd >7 ppb) over the Mine Block intrusion and the Baker zone. At the bog at the northern end of Shorty Lake, the difference in results between the west side and east side are not as clear cut, in fact, a spot high of 23.9 ppb Pd occurs on the east side, furthest from the Baker zone. The results of Pd by ashed-ICP analyses do not show the same level of contrast between background sites and sites near the Baker zone and do not show any obvious pattern at the bog at the north end of Shorty Lake.

Platinum in peat by fire assay and ashed-ICP are similar to Pd, but not as many sample sites near the Baker zone were elevated or anomalous. Once again, the highest Pt result (3.1 ppb) came from the east side of the bog at the north end of Shorty Lake. As with Au, other than the general pattern of higher levels near the Baker zone, there is very little corroboration of the spot highs between the 2 methods of analysis.

Nickel (Figure 21), Cu and Cr in peat determined by Enzyme Leach^{SM} show a very distinct and consistent pattern of elevated to anomalous levels near the Baker zone. All of these elements returned higher levels from the west side of the bog at the north end of Shorty Lake. This is good evidence for the presence of weakly bound (amorphous) metals hydromorphically dispersed from the Baker zone and overlying till. All PGE results by Enzyme Leach^{SM} were below detection limit.

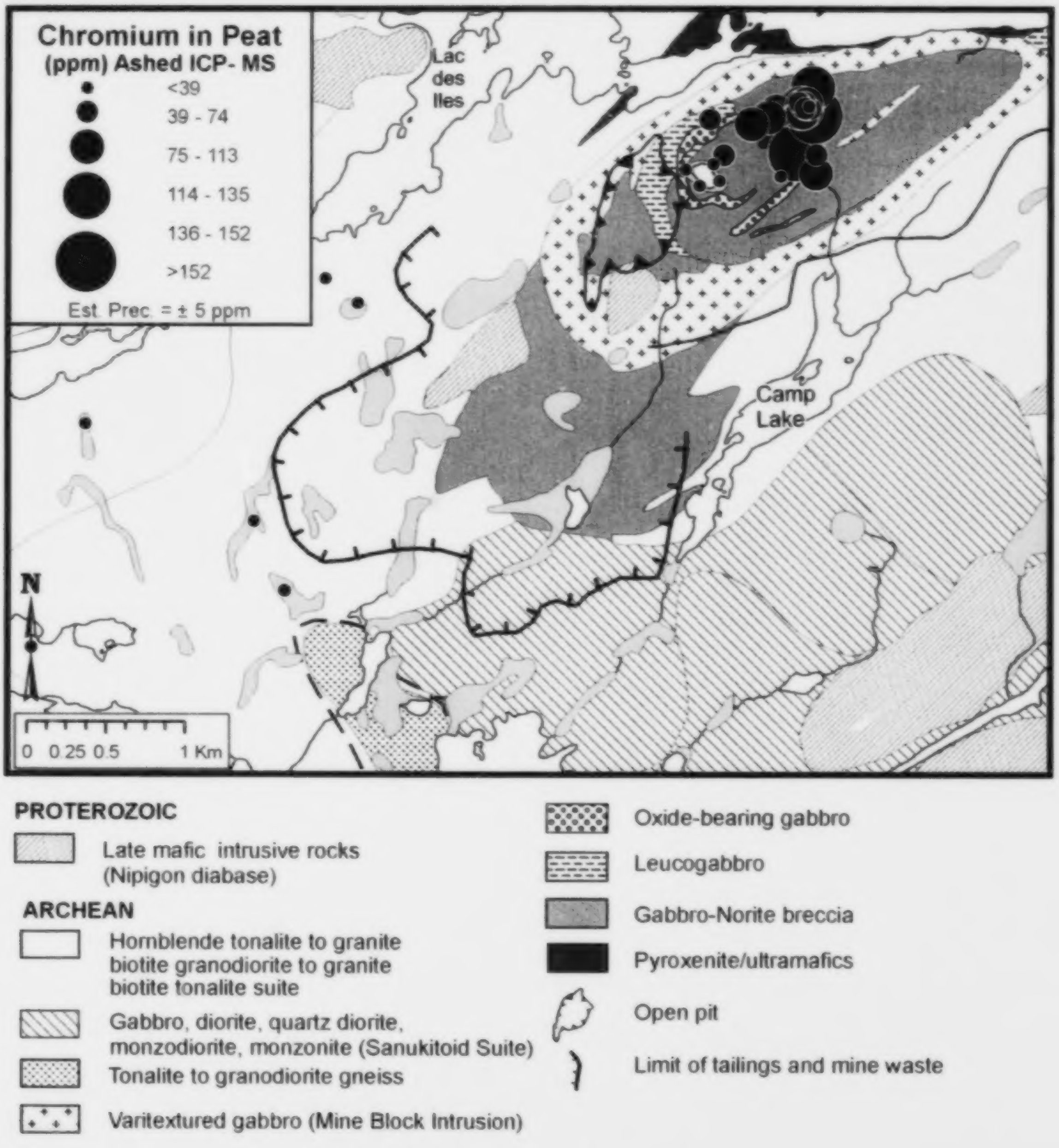
Chromium in Peat
(ppm) Ashed ICP- MS
<39
39 - 74
75 - 113
114 - 135
136 - 152
>152
Est. Prec. = ± 5 ppm
Lac des Iles
Camp Lake
N
0 0.25 0.5 1 Km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Tonalite to granodiorite gneiss
Varitextured gabbro (Mine Block Intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite/ultramafics
Open pit
Limit of tailings and mine waste

Figure 19. Chromium in peat, Lac des Iles area.

Stream Sediments

Organic stream sediments were sampled from 4 creeks as follows: 1) an ephemeral creek draining into the bog at the north end of Shorty Lake; 2) the creek draining southward from Shorty Lake; 3) a small creek draining eastward into Shorty Creek; and 4) a creek that drains into Camp Lake underlain by tonalite. Elevated to anomalous levels of Ni and Cr were obtained from organic sediment at the north end of Shorty Lake. Levels of these 2 metals gradually decrease down drainage towards Camp Lake. The creek underlain by tonalite returned significantly lower levels of these metals. Copper is high at the north end

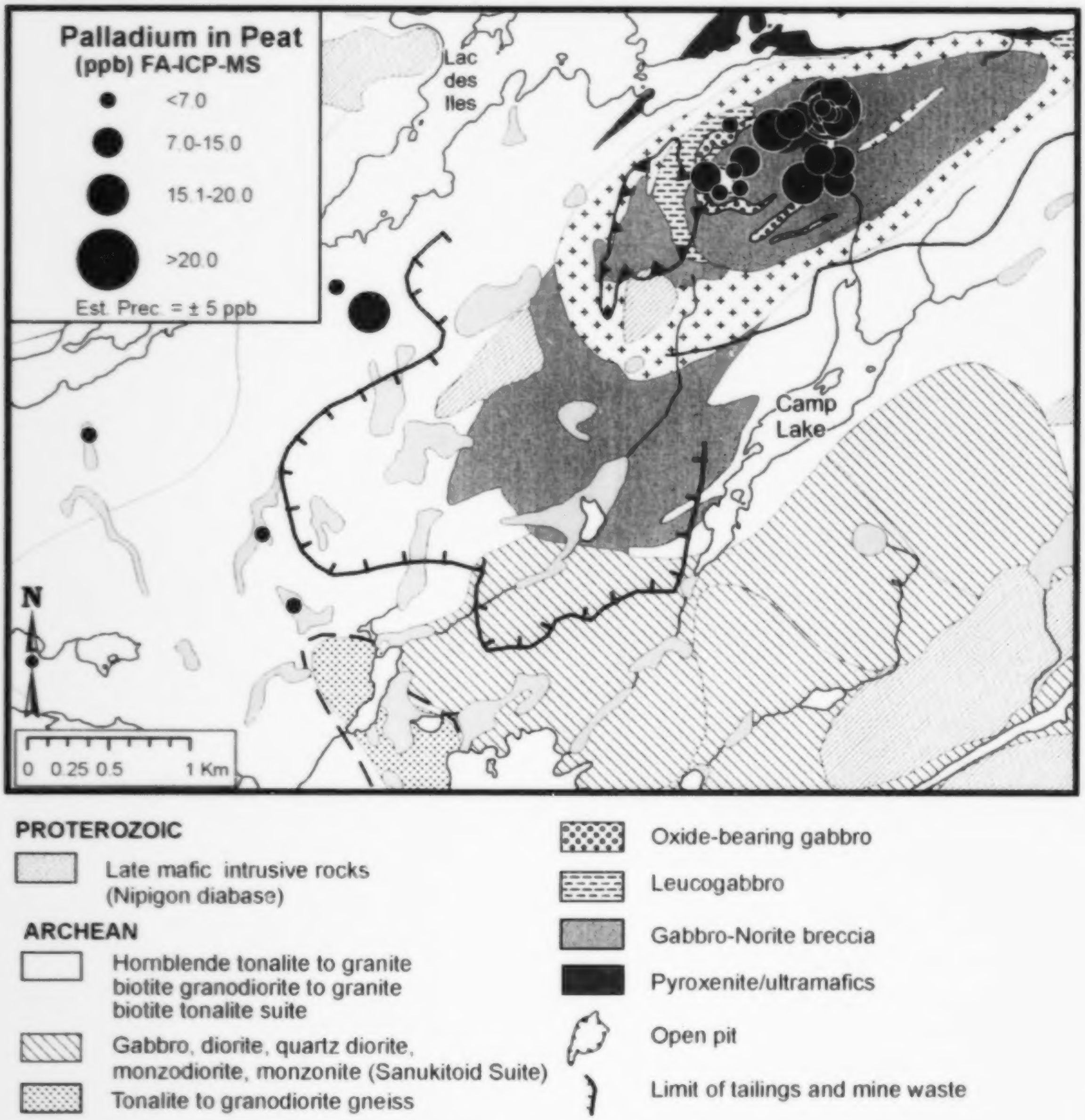
Palladium in Peat
(ppb) FA-ICP-MS
<7.0
7.0-15.0
15.1-20.0
>20.0
Est. Prec. = ± 5 ppb
Lac des Iles
Camp Lake
N
0 0.25 0.5 1 Km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Tonalite to granodiorite gneiss
Varitextured gabbro (Mine Block Intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite/ultramafics
Open pit
Limit of tailings and mine waste

Figure 20. Palladium in peat, Lac des Iles area.

of Shorty Lake, but similar levels were also obtained from the creek draining southward from Shorty Lake. The level of Cu in the organic sediment of the creek underlain by tonalite is not significantly lower that the Cu levels in the sediment south of Shorty Lake.

The response of precious metals in organic stream sediment around the Baker zone is weak. The most significant anomaly came from a small creek entering Shorty Creek south of the Baker zone. Stream water at this site was also anomalous. In addition, anomalous gold was obtained in sediment from the sample site further down Shorty Creek below the entry point of this small creek. Precious metals in the organic stream sediment of the creek underlain by tonalite were consistently low.

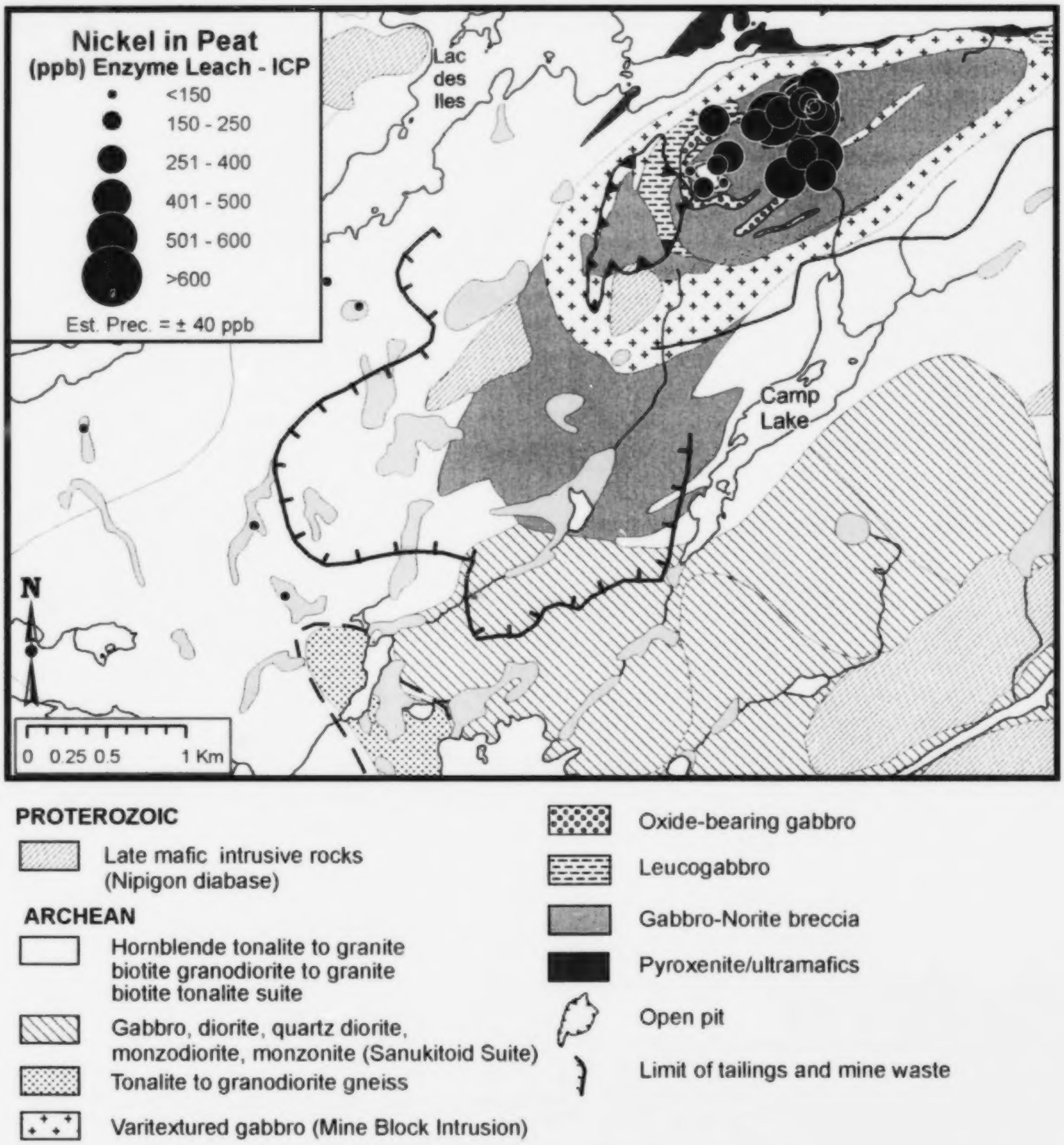
Nickel in Peat
(ppb) Enzyme Leach - ICP
<150
150 - 250
251 - 400
401 - 500
501 - 600
>600
Est. Prec. = ± 40 ppb
Lac des Iles
Camp Lake
N
0 0.25 0.5 1 Km
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
ARCHEAN
Hornblende tonalite to granite biotite granodiorite to granite biotite tonalite suite
Gabbro, diorite, quartz diorite, monzodiorite, monzonite (Sanukitoid Suite)
Tonalite to granodiorite gneiss
Varitextured gabbro (Mine Block Intrusion)
Oxide-bearing gabbro
Leucogabbro
Gabbro-Norite breccia
Pyroxenite/ultramafics
Open pit
Limit of tailings and mine waste

Figure 21. Nickel (determined by Enzyme Leach^{SM} – ICP–MS) in peat, Lac des Iles area.

Inorganic stream sediment was obtained from 4 drainages: 3 near the Baker zone and one off the Mine Block intrusion. The only significant Ni, Cu, Pt, Pd and Au levels came from below the mine road entering Camp Lake. Chromium, however, was strongly anomalous at 2 sample sites in the creek north of the Baker zone, which drains towards the bog at the north end of Shorty Lake.

Summary

The Lac des Iles study area is well suited for using till for mineral exploration. Dispersal trains or plumes can be observed in both heavy mineral (chromites and chrome andradite garnet) and till (C-horizon, –250 mesh) geochemistry results (Ni, Cr, Cu and Co). Despite the low numbers of grains of platinum group metals recovered from heavy mineral concentrates, their occurrence is considered important and the presence of any of these indicates that mineralization may be located nearby (probably within 1000 m).

Regional dispersal trains for elements, such as Mg, Cr, Ni and Co, associated with the Mine Block intrusion can be detected for approximately 4 km beyond its western (down-ice flow) margin. Regional dispersal trains range from 5 to 7 km in length and about 1 to 2 km in width. Dispersal trains of Pt, Pd and Au are not as well defined and tend to be very short, less than 1 km in length, due to the initial, low concentrations of these elements in C-horizon till samples from the Lac des Iles area. The behaviour of Ni in the soil environment is similar to that of Pt and can be used as a proxy. The behaviour of Cu in the soil environment is similar to that of Pd with respect to relative mobility of these elements.

Patterns of the associated trace elements, such as Ni, Cr and Mg, indicate that, although the rocks of the Mine Block intrusion and surrounding areas are very similar in appearance, there are significant variations in trace element chemistry (*see* Figure 11). In general, the associated trace elements form larger dispersal trains than PGEs due to their greater initial abundance making them larger targets for mineral exploration surveys using C-horizon till samples

Most the elements of interest occur in greater abundance in C-horizon samples than in B-horizon samples. This might lead to the conclusion that sampling the C-horizon might be the best method for mineral exploration of PGEs. However, for several trace elements, the results of B-horizon samples are useful. For Ni, Mg and Cr, B-horizon sample results target only the heads of dispersal trains defined by C-horizon samples. The B-horizon targets are much smaller; however, there is some evidence of downslope movement of elements and blurring of the target area.

Humus samples appear to be contaminated by airborne dust derived from mining operations. This is best illustrated with Pd and Pt, elements that have initially low natural concentrations (*see* Figure 12). Whereas glacial dispersal (C-horizon results) has created geochemical gradients toward the southwest, the geochemical gradients in the humus samples are generally eastward. Significantly higher Ni-Cu ratios in surface waters compared to groundwaters, Baker zone rocks and data from all other case study areas may be further evidence of this anthropogenic input.

The spatial association of elevated Cu-Ni-Cr±PGE in deep (piezometers) waters around the Baker zone in this study is consistent with the findings of Hattori and Cameron (2004). In particular, the higher levels of Ni on the west side of Shorty Lake (closest to the Baker zone) compared to the east side seems to indicate a higher geochemical flux due to the Baker zone. Most observed geochemical patterns from deeper waters (groundwater springs and piezometer waters) are spatially related to bedrock mineralization.

The general weak precious metals response in waters downslope from the Baker zone, in particular, towards Shorty Lake, may be due to low levels and/or interception (fixation) by organic matter. The latter is evident because fire assay for precious metals yielded a good metals response in the peat.

spatially associated with the Baker zone. In terms of pathfinder elements, both the Enzyme Leach^{SM} analysis and conventional ICP analysis of organic peats gave an excellent Cu-Ni-Cr response around the Baker zone topographic high.

The results of this project have defined several vectors to possible undetected mineralization (Figures 11 and 22). These include significant multi-media Cr anomalies vectoring to the northeast shore of Shorty Lake and multi-media Ni-Cu-Au-PGE anomalies vectoring to the area south of Shorty Lake.

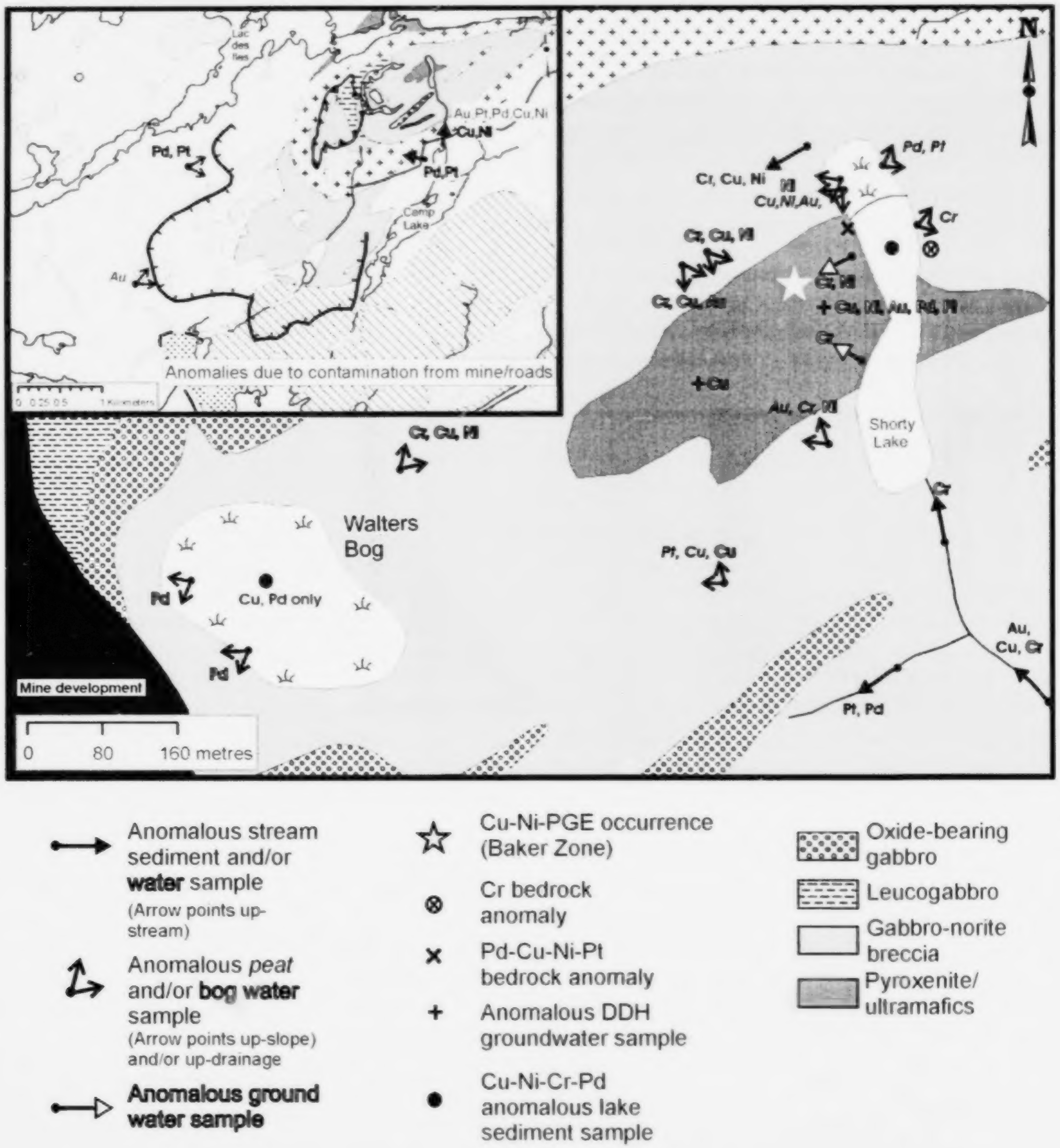

Figure 22. Geochemical anomaly $(>+2\sigma)$ vector map for water, peat and stream sediment, Lac des Iles area.

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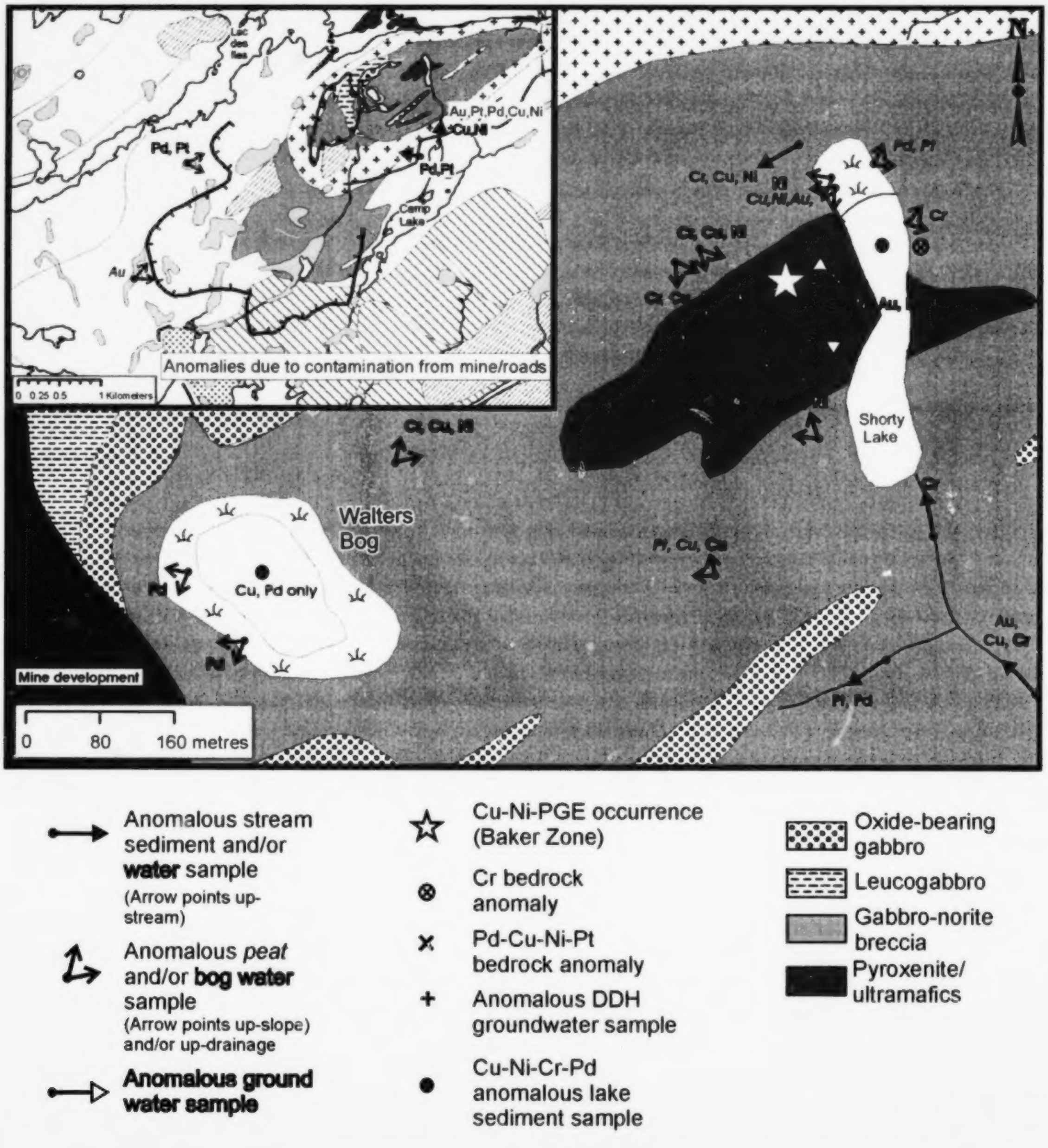


Figure 22. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, peat and stream sediment, Lac des Iles area.

TIB LAKE STUDY AREA

Introduction

The Tib Lake study area is in a bedrock-dominated terrain underlain by ultramafic to mafic intrusive rocks, commonly gabbro in the northeast and granite in the southwest. The terrain is a regional area of high elevation and has local relief up to 30 m. A map of the distribution of surficial sediments is presented as Map 2 (back pocket).

The bedrock surface, where recently exposed, is commonly well polished, striated and contains large- and small-scale meltwater erosion marks such as transverse troughs, cavettos and muschelbruke. Weathered or long-exposed bedrock surfaces tend not to retain the striation record due to their coarse-grained nature. The dominant direction of ice flow recorded from striae is toward 245°, however, variation in striae orientation ranges from 235 to 255°. At one site, striations oriented at 183° were observed. It was not possible to determine the age-relation of these striae to the more common southwest direction that, unfortunately, were not present at the site.

Till associated with the dominant ice flow direction is usually very thin and discontinuous, but was observed as thick as 3 m. It is commonly a stony, massive, slightly silty, very fine- to very coarse-grained sand. Analysis of 6 samples of till (C-horizon) average approximately 74% sand, 25% silt and 1% clay-size particles in the matrix. The till appears to thicken along the flanks and in the down-ice direction of bedrock knobs. An actively flowing wet-based glacier deposited the till in the Tib Lake area. The occurrence of striae, large- and small-scale meltwater erosion features and the common occurrence of interbedded stratified sediments and tills in lee-side cavity fills support this conclusion. Using till for mineral exploration in the Tib Lake area is recommended because it was deposited beneath an actively flowing glacier; however, the till is commonly very thin, discontinuous and/or covered by sand. These factors make locating sites and appropriate soil horizons suitable for sampling difficult.

Soils developed in till at Tib Lake generally consist of a thin to moderately thick (1 to 8 cm) humus layer, a thin to non-existent zone of eluviation (Ae), usually less than 2 cm thick, and a B-horizon 30 to 50 cm thick. The B-horizon consists of a 10 cm dark orange brown Bf-horizon that is enriched in iron and a 20 to 40 cm thick yellow-brown to brown Bm- and/or BC-horizon. B-horizons developed in till contain more silt- and clay-size particles than the parent material (C-horizon) due to the breakdown and relocation of particles of the original parent material by soil forming processes. In a large part of the Tib Lake area, however, a veneer of sand overlies the till and the Type 5, "geogenic", soil geochemical profile type occurs (Klassen 2003). The sand cover can be over 1.5 m thick. In these areas, B-horizon soils are developed in sand, not till and are not recommended for sampling.

Stratified glaciofluvial sand and gravel is found in large and small lee-side cavity fills, sinuous ridges (eskers) and in small minor moraines within the Tib Lake area. Sand of glaciolacustrine origin occurs beneath the small plains in the lower elevation areas. This material is a hindrance to the utilization of till for mineral exploration in this area (*see* Map 2, back pocket).

Till: Glacial Dispersal

Till can be used in the Tib Lake study area for mineral exploration. However, use of this media is more difficult here than in the Lac des Iles study area because of the difficulty in obtaining C-horizon till samples. There are several reasons for this. The till is thin, discontinuous and commonly buried beneath sand. As well, the abundance and size of large lee-side cavity fills composed of sand, gravel and flowtills are a hindrance to mineral exploration. These characteristics make it difficult and frustrating to get an appropriate amount and distribution of till samples to help in defining dispersal trains or sources of mineralization. However, the till was deposited from the base of an active glacier, so samples of C-horizon till do reflect bedrock composition up ice-flow direction from the sample site and provide clues as to the bedrock surface covered by glacial and postglacial sediments. Although no well-defined dispersal trains were identified, some of the geochemical results obtained from collected samples are of interest. Known mineral showings are not well reflected in till geochemical results as a result of sample distribution and/or low initial concentrations in the showings.

HEAVY MINERAL RESULTS

Analyses to obtain the overall heavy mineral assemblage in till were completed by GeoLabs on 8 samples from the Tib Lake area. The average heavy mineral composition consists of about 69% clinopyroxene, 9% calcic amphibole, 9% orthopyroxene and minor amounts (<2%) of fayalite, forsterite, ilmenite, epidote and titanite. These minor constituents are of interest in mineral exploration (Averill 2001).

In addition, 4 heavy mineral samples, 2 till and 2 stream sediments, were processed and analyzed by Overburden Drilling Management Limited (ODM) of Nepean, Ontario. The methodology followed was developed at ODM and has been summarized in several publications (Morris and Kaszycki 1997; Averill 2001; McMartin and McClenaghan 2001). The reports provided by ODM concentrate on the important minor constituents or indicators of mineralization of the heavy mineral assemblages. The results provided by ODM are contained in MRD 154.

Overburden Drilling Management Limited recognized several mineral assemblages within the Tib Lake set of samples. Pigeonite dominated the assemblages that also included diopside, titanite and/or epidote.

No mineral grains containing platinum, palladium or gold were recovered from the 4 samples collected in the Tib Lake area. Very few other indicator minerals for MMSIM® or KIM interpretations were recovered. A till sample (03-PJB-173), collected from the up-ice side of the area cleared at the Kuhner occurrence, contained 3% fayalite, 1 grain of low-chrome diopside, 1 grain of red rutile and trace amounts of sillimanite. The stream sediment (03-PJB- 182) sample collected from the small creek that drains the area of the Kuhner occurrence also contained trace amounts of sillimanite and 5% fayalite, but none of the other minerals. A sample of till collected approximately 1.5 km down ice-flow from the Kuhner occurrence contained 5% fayalite and 2% forsterite, but none of the other minerals. The other stream sediment sample (03-PJB-190) collected near the mouth of the stream that drains Coons Lake contained 5% fayalite and no other indicator minerals.

C-HORIZON TILL SAMPLE GEOCHEMICAL RESULTS

C-horizon till is material that was deposited directly from the glacier with little to no alteration as a result of soil-forming processes or weathering. Samples of till indicate the physical dispersal of rock fragments and minerals from bedrock sources by glaciers in the down-glacier ice-flow direction. Sampling density was not sufficient to delineate discrete dispersal trains associated with mineralization, however, the distribution and values obtained from the geochemical analysis of collected samples (–250 mesh) are of interest for several elements. In general, the northern part of the Tib Lake intrusion, which has not received the same attention as the southern part during mineral exploration programs, contains elevated values $(>\bar{x}+1\sigma <\bar{x}+2\sigma)$ in C-horizon till samples of Pt, Pd, Cu, Co and Cr (Figure 23). An interesting elevated Au value in till occurs approximately 1.5 km southwest of Empry Lake.

The results discussed below are based on fire assay and ICP analyses for PGEs and ICP analysis for the other trace elements. A summary of the results is presented in Table 5. Results for all the geochemical analyses performed are available in MRD 154, published separately from this report.

Platinum Group Elements

There is only one C-horizon till sample (Tib-Soil-2014) that contains anomalous Pt in the Tib Lake case study area. It is located a short distance down-ice flow of the western margin of the intrusion. Elevated levels of Pt in till occur sporadically along the southeast to northwest margin of the intrusion including the Kuhner occurrence and down ice-flow direction from there.

Two till samples were anomalous with respect to Pd (Tib-Soil-2012, Tib-Soil-2019). One sample, Tib-Soil-2012, occurs along the newly defined northern edge of the intrusion (Stone et al. 2004) and the other, Tib-Soil-2019, is located about 1.2 km north of the fire tower on the Dog River Road near a Proterozoic mafic intrusive gabbro dike. Elevated Pd in till also occurs in isolated spots along the margin of the Tib Lake intrusion.

A till sample (Tib-Soil-2017) collected approximately 1.2 km southwest of Empry Lake contained anomalous Au (17.6 ppb). Other samples with elevated gold values occur nearby within an area mapped as biotite tonalite to granodiorite in the vicinity of the Proterozoic dike (Stone et al. 2003).

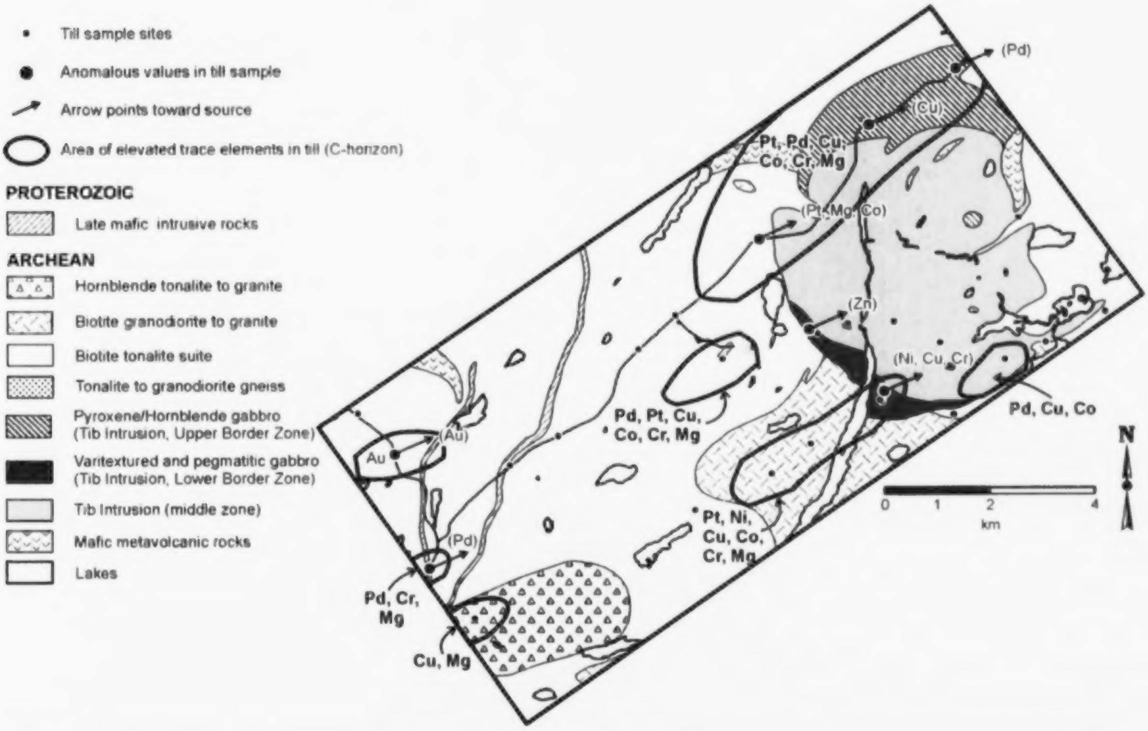

Till sample sites
Anomalous values in till sample
Arrow points toward source
Area of elevated trace elements in till (C-horizon)
PROTEROZOIC
Late mafic intrusive rocks
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Tonalite to granodiorite gneiss
Pyroxene/Hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (middle zone)
Mafic metavolcanic rocks
Lakes
(Pd)
(Cu)
Pt, Pd, Cu, Co, Cr, Mg
(Pt, Mg, Co)
(Zn)
(Ni, Cu, Cr)
Pd, Cu, Co
Pd, Pt, Cu, Co, Cr, Mg
(Au)
Au
Pt, Ni, Cu, Co, Cr, Mg
(Pd)
Pd, Cr, Mg
Cu, Mg
0
1
2
4
km
N

Figure 23. Distribution of anomalous ($\bar{x}+2\sigma$) samples and areas of regionally elevated PGE and associated elements from C-horizon till samples with vectors to source areas, Tib Lake study area. Elements in brackets are anomalous values in individual till samples and element assemblages not in brackets are related to areas of elevated concentrations.

Associated Elements

Broad, regional, dispersal trains for several trace elements that are commonly associated with Pt and Pd occur in the Tib Lake study area. The distribution of Cu, Cr, Mg, Co and, to a lesser extent, Ni in C-horizon till samples are similar. Contouring of trace element concentration distributions using inverse distance weighting techniques produces regional dispersal trains of about 3 to 7 km in length and 2 to 3 km in width for Cu, Ni, Cr, Mg and Co, which are oriented roughly parallel to the latest ice flow direction (240 to 250°).

There are 2 main areas of interest based on C-horizon till results: the area surrounding the Kuhner occurrence and the northern part of the Tib Lake intrusion (*see* Figure 23). Minor areas of interest occur sporadically along the margin of the intrusion.

Anomalous values in Cu, Ni and Cr content were obtained in a C-horizon till sample (Tib-Soil-2026) collected from a small trench located approximately 200 m north of the Kuhner occurrence. The area immediately up ice-flow direction from this site should be investigated further as stream sampling also returned interesting results (*see* Figures 23 and 28). A sample (Tib-Soil-2014) with an anomalous concentration of Mg occurs down ice flow of the western margin of the northern part of the Tib Lake intrusion. Elevated values of Pd, Cu, Ni, and Co also occur at this site and along the northern margin of the intrusion where anomalous Cu (Tib-Soil-2013) and Pd (Tib-Soil-2012) C-horizon till samples were collected.

Till: Soil Profile Geochemistry

Following deglaciation, the materials making up the land surface were exposed to weathering and soil-forming processes. The parent material (C-horizon) of the soil begins to alter physically and chemically in response to these processes and other soil horizons form. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter) was also sampled during this project.

In all case study areas that have soils developed entirely in till, there is, in general, a decline in concentrations of Pt, Pd, Ni, Cu, and Cr up through the soil profile from the C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7), of the 5 basic geochemical profile types proposed by Klassen (2003). The majority of sites in the Tib Lake study area, however, have the Type 5, "geogenic", profile, that is, different materials, stratigraphy, within the soil profile or a change in parent material through the soil profile (Klassen 2003; *see* Figure 7). There is also a chemical disjunct between the surface postglacial sand and till parts of the mineral soil layers. Sites like this were avoided for sampling B-horizon and humus as interpretation and tracing anomalies back to their source is very difficult. As a result, few B-horizon till samples and samples of humus formed over complete soils developed in till could be collected and analyzed.

Sites that did contain the 2 mineral soil horizons developed in till, commonly fall into the Type 1, "leaching", profile, that is, a net downward increase in element concentration for Cu, Cr and Co (Klassen 2003). Variations in Pt, Pd, Au, Ni and Zn concentration between the various soil horizons were less than the error of laboratory measurements so little can be said about their geochemical soil profiles. However, the general trends observed for Pt, Pd and Ni were similar to Cu, Cr and Co (Type 1: Klassen 2003) in the Tib Lake case study area. Results of the analysis of B-horizon and humus samples are included in MRD 154.

Palladium, Ni and Co concentrations in a B-horizon till sample (Tib-Soil-1026) were anomalous ($\bar{x}+2\sigma$) at the same locality where anomalous values in Cu, Ni and Cr content were obtained in a C-horizon till sample (Tib-Soil-2026), approximately 200 m north of the Kuhner occurrence. Chromium was anomalous in one B-horizon sample collected at the Kuhner occurrence and an anomalous value of Cu occurs in sample Tib-Soil-1016, which is not associated with elevated ($>\bar{x}+1\sigma<\bar{x}+2\sigma$) Cu in the C-horizon.

In the Tib Lake study area, B-horizon till and humus sampling is not as useful as sampling C-horizon till for mineral prospecting. The extensive areas covered by a surface layer of postglacial sand make collecting B-horizon till samples impossible for much of the area. Till (C-horizon) can be used in the Tib Lake area for mineral exploration. However, it is more difficult here than at the Lac des Iles study area because of the difficulty in obtaining C-horizon till samples.

Lake Sediments

The Tib lake study area has occurrences of Cu-Ni-PGEs in bedrock, but no lake sediment anomalies, except for one gold anomaly of 25 ppb (Dyer and Russell 2002). The lack of lake sediment Cu-Ni anomalies at the Tib Lake intrusion is likely, in part, due to a paucity of lakes near the Lower Border zone, which hosts most of the known occurrences. Only 2 water bodies have Lower Border zone rocks within their drainage catchments; the wide part of the East Dog River and the lake that returned the 25 ppb Au analysis. The original lake sediment sampling of the East Dog River failed to obtain a sample (sand and rock bottom). Re-sampling under this project obtained a suitable sample, but its location is upstream of the inlet of the creek that passes near the Kuhner occurrence. Consequently, no anomalous values were obtained in this lake sediment sample. Re-sampling of the Au anomalous lake during this project returned values of 12.9, 1.5 and 2.1 ppb by AR-ICP–MS, FA–ICP–MS and INAA, respectively. This weaker signal may be due to the nugget effect, an inherent difficulty when sampling and analyzing for Au.

Lithogeochemistry

Thirteen bedrock samples were collected in the Tib Lake study area. Five were collected from the Jewelweed occurrence, 3 from the Kuhner occurrence, 1 from the Road occurrence, 3 from the Tib Lake intrusion itself (away from any known occurrences) and 1 sample of tonalite from outside the intrusion. The Kuhner occurrence returned anomalous levels of Au (120 ppb), Pd (745 ppb), Pt (246 ppb), Ni (2240 ppm), Cr (848 ppm) and Cu (1080 ppm) from a sample with <1% fine disseminated sulphides. This is the most anomalous PGE-Ni-Cu-Cr rock sample obtained in the Tib Lake study area. The Jewelweed occurrence returned the next highest levels of Pd (459 ppb), Pt (45 ppb) and Au (53 ppb), but relatively low levels of Ni (150 ppm), Cr (116 ppm) and Cu (50 ppm). The Road occurrence returned no significant precious metals and low levels of Ni (294 ppm), Cr (138 ppm) and Cu (115 ppm).

Hydrogeochemistry

Compared to the other case study areas, the Tib Lake study area has the second lowest levels of metals in waters (only the Tarrison Lakes study area is lower). In general, Ni and Cu levels are very low and the Ni to Cu ratio in waters is significantly lower than at the Lac des Iles study area.

BOG WATER

The results of bog water (sump) chemistry show excellent contrast between sites located on the Tib Lake intrusion and those away from the feature. On the Tib Lake intrusion, 2 sites were consistently highest in metals: a groundwater seep (high in Pt, Au, and Ni) within 300 m downslope of the Road occurrence and a bog (site Tib-Bog-1) (high in Cr, Cu, Ni and Pd) east of the Kuhner area, approximately 550 m upstream from the anomalous creek water site mentioned below. This is additional evidence of a possible point source east of the Kuhner occurrence.

STREAM WATER

A total of 21 stream waters were collected within the Tib case study area: 15 streams located on the Tib Lake intrusion and 6 away from the intrusion to the southwest. Outside of the Kuhner and Road

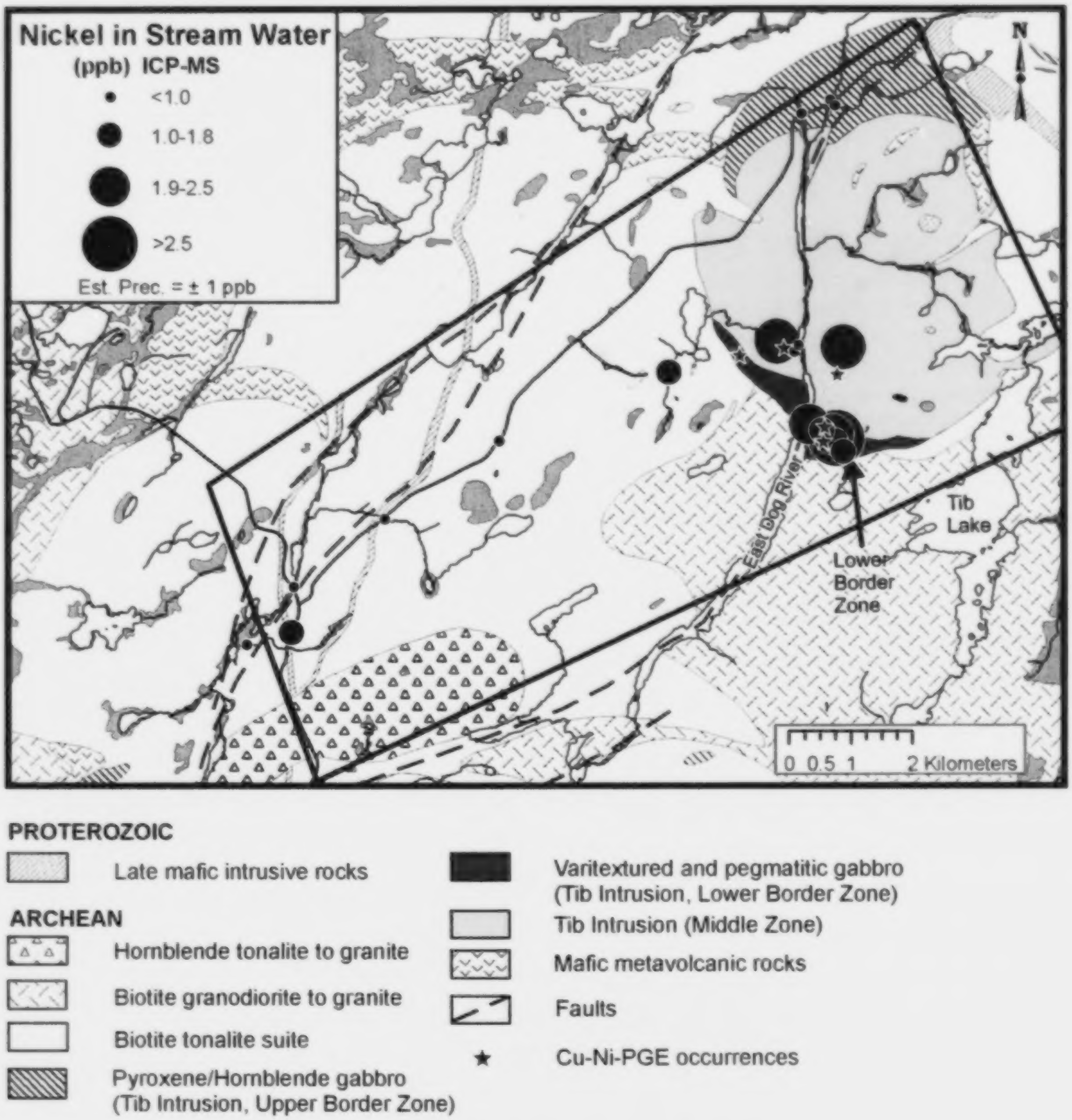

Nickel in Stream Water
(ppb) ICP-MS
<1.0
1.0-1.8
1.9-2.5
>2.5
Est. Prec. = ± 1 ppb
N
East Dog River
Tib Lake
Lower Border Zone
0 0.5 1 2 Kilometers
PROTEROZOIC
Late mafic intrusive rocks
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Pyroxene/Hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (Middle Zone)
Mafic metavolcanic rocks
Faults
Cu-Ni-PGE occurrences

Figure 24. Nickel in stream water, Tib Lake study area.

occurrences, the presence of the Tib Lake intrusion did not impart a significant Ni-Cu-Cr-PGE-Au geochemical signature to the stream waters sampled. Only a few samples on the Tib Lake intrusion, located outside the influence of an occurrence, returned a Pd, Pt or Ni (Figure 24) level significantly higher than found away from the intrusion. Levels of Cu and Cr were only above regional background near the Kuhner occurrence.

Hydrogeochemistry of metals near the Road and Kuhner occurrences, although at low levels, demonstrates that hydromorphic dispersion is occurring. Nickel and Cu (Figure 25) are present at levels greater than regional background in the creek located downslope of the Kuhner occurrence. This response can be related to Kuhner occurrence mineralization. However, Cr, Pd and Pt are highest

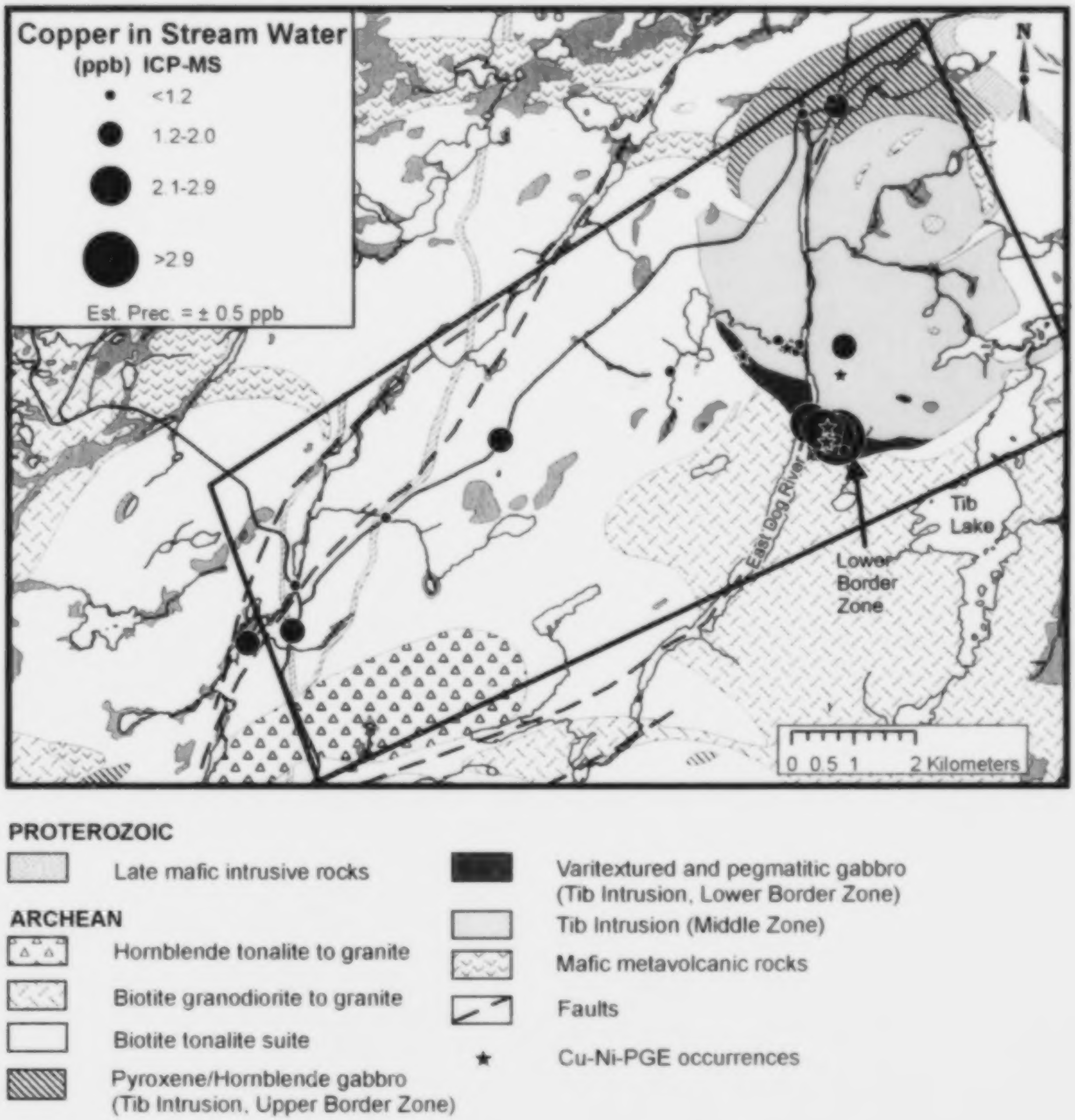

Copper in Stream Water
(ppb) ICP-MS
<1.2
1.2-2.0
2.1-2.9
>2.9
Est. Prec. = ± 0.5 ppb
N
East Dog River
Tib Lake
Lower Border Zone
0 0.5 1 2 Kilometers
PROTEROZOIC
Late mafic intrusive rocks
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Pyroxene/Hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (Middle Zone)
Mafic metavolcanic rocks
Faults
Cu-Ni-PGE occurrences

Figure 25. Copper in stream water, Tib Lake study area

upstream of the Kuhner occurrence indicating (vectoring) to a source more than 300 m to the east of the Kuhner occurrence. Gold in stream water is also present at very low levels; most of the highest results occur on the Tib Lake intrusion, specifically near the Kuhner and Road occurrences.

Peat

Organic peat was obtained at 8 sites: 4 on the Tib Lake intrusion and 4 away from the intrusion. Results for Ni, Cu and Cr from sites on the Tib Lake intrusion are distinctly elevated compared to sites away from the intrusion. Nickel is consistently greater than 10 ppm (Figure 26) and Cu greater than 20 ppm from the

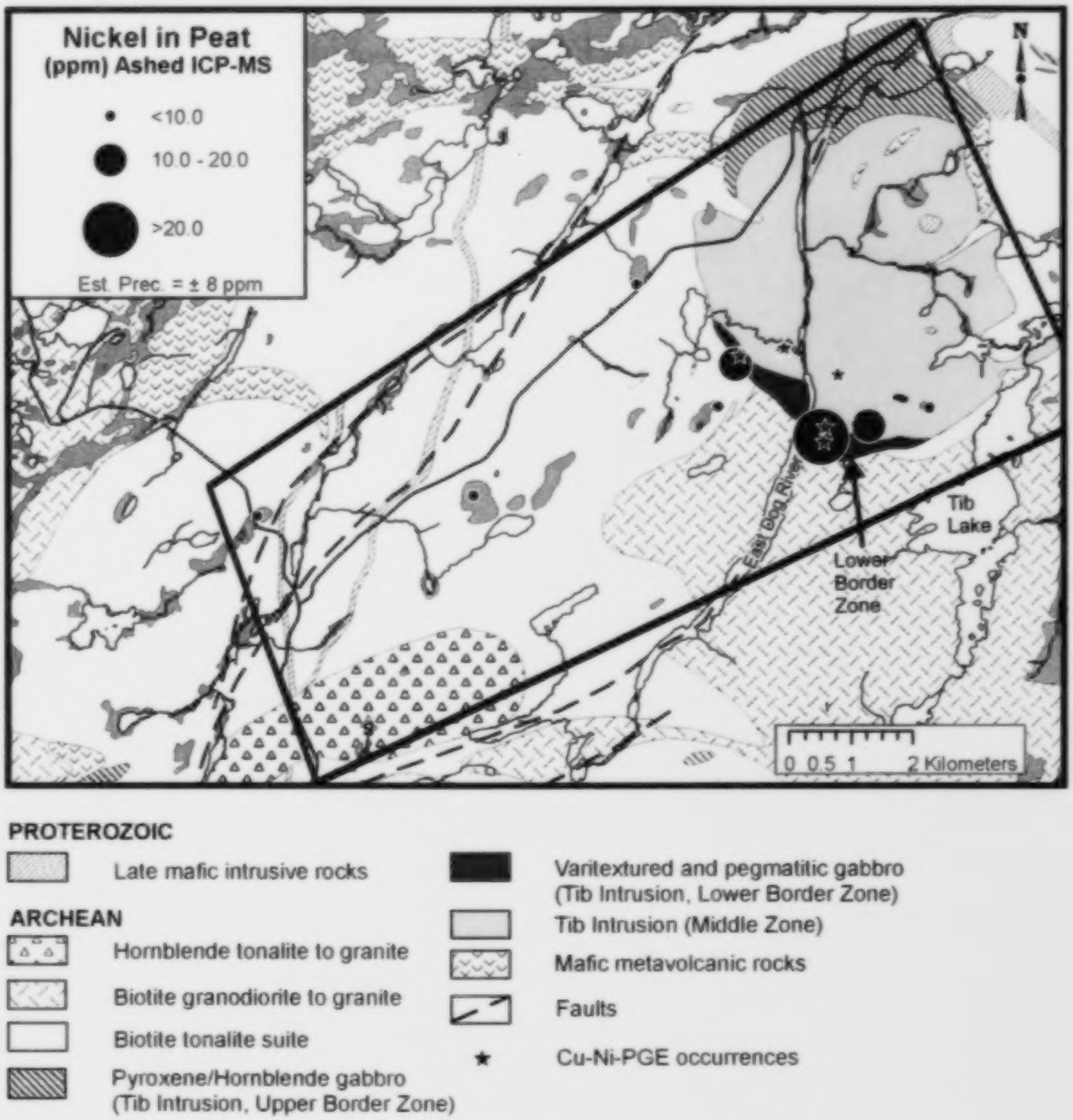

Nickel in Peat
(ppm) Ashed ICP-MS
<10.0
10.0 - 20.0
>20.0
Est. Prec. = ± 8 ppm
N
East Dog River
Lower Border Zone
Tib Lake
0 0.5 1 2 Kilometers
PROTEROZOIC
Late mafic intrusive rocks
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Pyroxene/Hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (Middle Zone)
Mafic metavolcanic rocks
Faults
Cu-Ni-PGE occurrences

Figure 26. Nickel in peat, Tib Lake study area.

sites on the Tib Lake intrusion. However, the highest Cu level of 45 ppm was obtained from a swampy area approximately 600 m southwest of the Lower Border zone. Chromium was only significantly above background (anomalous) in peat at 2 sites in the vicinity of the Kuhner occurrence. The peat site closest to the Kuhner occurrence returned the highest (anomalous) level of Cr, Co, Ni, Pd (FA–ICP–MS) and Pt (FA–ICP–MS). At site Tib-BOG-1, approximately 800 m east of the Kuhner occurrence, the second highest level of Cr was obtained, the second highest Ni and the third highest Cu. This again indicates potential for a point-source mineralization occurring east of the Kuhner occurrence.

Of the precious metals, Pt displays the best contrast between sites located on and away from the Tib Lake intrusion. Most of the high Pd values came from sites nearest the Lower Border zone. There is very little corroboration between Au analyzed by the 3 methods (ashed-ICP–MS, FA–ICP–MS, INAA). The site nearest the Kuhner occurrence returned the highest level of Au by INAA, however, the highest level of Au by fire assay was obtained from a site southwest of the Tib Lake intrusion. This is another example of how the nugget effect is a problem for reproducible and accurate determination of Au.

The results of Enzyme Leach^{SM} analysis of peat show that Ni, Cu and Co have the best response with elevated to anomalous levels spatially associated with the Lower Border zone. Chromium shows no response at the Lower Border zone and Au and PGEs were all below detection limit. Site Tib-Bog-1, located approximately 800 m east of the Kuhner occurrence, had the highest result for Ni and Co by Enzyme Leach^{SM}.

Stream Sediments

Organic stream sediments were obtained from 7 sample sites: 5 from the Lower Border zone area and 2 well away from the Tib Lake intrusion to the southwest. The highest levels of Cu, Co, Cr, Ni, Au and PGEs occur in the vicinity of the Kuhner occurrence. Three sites account for most of the anomalous results for these elements: Tib-SS-1, Tib-SS-3 and Tib-SS-4; the latter 2 sites are located in the vicinity of the Kuhner occurrence. This geochemical signal may, in part, be due to the Kuhner occurrence, but, just as with the other media discussed above, the results seem to indicate another source further to the east of the Kuhner occurrence. Site TIB-SS-1, located approximately 1.5 km to the north, is within about 100 m of an area likely stripped to uncover rocks prospective for Ni-Cu mineralization. The rock sample obtained at this site returned only weakly anomalous levels of these metals.

Inorganic stream sediment was collected at 17 sites of which 15 are located on the Tib Lake intrusion. Although the number of background sites for comparison are few, it is clear that Ni and Cr are distinctly elevated over the Tib Lake intrusion relative to the sites over granitic terrain. Copper is only elevated over background in the Lower Border zone area.

The highest levels of Ni and Cu (>30 ppm) and Cr (>26 ppm; Figure 27) occur near the Road and Kuhner occurrences. Palladium and Pt are consistently elevated in inorganic stream sediment over the Tib Lake intrusion compared to background areas. The highest levels of PGEs were obtained in the area of the Kuhner occurrence. It is again apparent that contribution to this geochemical signal is being made from the area east of the Kuhner occurrence stripped area. Anomalous levels of Pd, Au and Cr were obtained from sediment at site Tib-SS-10, located in the northeast part of the study area, underlain by Upper Border zone of the Tib Lake intrusion.

Humus

Samples of humus were collected downslope of the Jewelweed (3 samples) and Road (4 samples) occurrences to determine if these modest Cu-Ni showings could impart a detectable signature useful for exploration. Topography at the 2 showings differs; the Jewelweed occurrence is flanked by steeper slopes than the Road occurrence. Ni and Cu (ashed-ICP) results are highest near the showings, displaying a general pattern of decreasing concentration downslope away from the occurrences. The Enzyme Leach^{SM} data for these elements show a similar trend at the Jewelweed occurrence, but the pattern at the Road

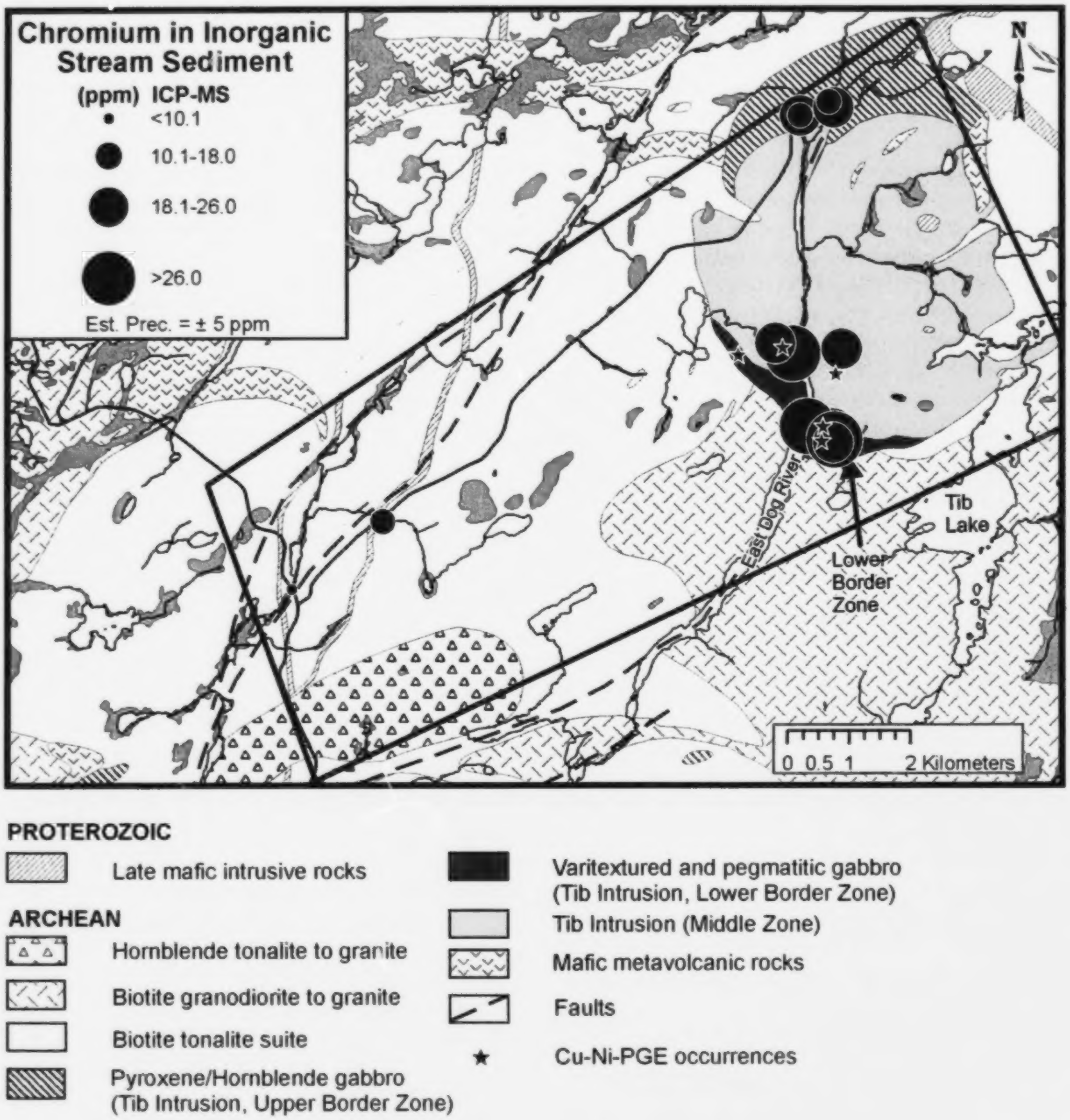

Chromium in Inorganic Stream Sediment
(ppm) ICP-MS
<10.1
10.1-18.0
18.1-26.0
>26.0
Est. Prec. = ± 5 ppm
N
East Dog River
Tib Lake
Lower Border Zone
0 0.5 1 2 Kilometers
PROTEROZOIC
Late mafic intrusive rocks
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Pyroxene/Hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (Middle Zone)
Mafic metavolcanic rocks
Faults
Cu-Ni-PGE occurrences

Figure 27. Chromium in inorganic stream sediment, Tib Lake study area.

occurrence is consistently low. The Cr (ashed-ICP) response is mixed; levels increase downslope from the Jewelweed occurrence, whereas at the Road occurrence, there is a weak decrease in concentration downslope. Chromium analyses by Enzyme Leach^{SM} were all below detection limit. Cobalt shows the same pattern by both methods, that is, highest levels near the Jewelweed occurrence and a lower flat response at the Road occurrence. Of the precious metals, only Pt (FA and ashed-ICP) displays a response at the Road occurrence that may reflect mineralization, however, levels do not exceed the estimates of precision. Palladium shows no pattern of dispersion, however, the levels in bedrock are very low as well. All the precious metals by Enzyme Leach^{SM} were below detection limit.

Nickel and Cu by conventional (total digestion) ashed-ICP show a weak but detectable response at both occurrences. The inconsistent and generally weak base metal response at the occurrences by the Enzyme Leach^{SM} digestion suggests that very little weakly bound (amorphous), hydromorphically dispersed Ni and Cu is present. The precious metals levels are low (close to detection limits) and are not significant compared to the estimates of precision for the analytical methods.

The data suggest that these modest occurrences are dispersing a weak but detectable base metal signature. Due to their higher initial levels at source, the metals Cu, Ni and Cr should be targeted using conventional analytical methods (e.g., ICP) with a total or near-total digestion method. The Enzyme Leach^{SM} results were inconsistent and displayed less contrast than the conventional total digestion ICP methodology.

Summary

Till can be used in the Tib Lake study area for mineral exploration. However, use of this media is more difficult here than at the Lac des Iles study area due to the difficulty in obtaining C-horizon till samples. Sampling density was not sufficient to delineate discrete dispersal trains associated with mineralization, however, the distribution and values obtained from the geochemical analysis of the samples collected are of interest for several elements. In general, the northern part of the Tib Lake intrusion, which has not received the same attention as the southern part during mineral exploration programs, contains elevated values in C-horizon till samples of Pt, Pd, Cu, Co and Cr (*see* Figure 23). An interesting elevated Au value in till occurs approximately 1.5 km southwest of Empry Lake. Anomalous values in Cu, Ni and Cr content were obtained in a C-horizon till sample (Tib-Soil-2026) collected from a small trench located approximately 200 m north of the Kuhner occurrence. The area immediately up ice-flow direction from this site should be investigated further as there are also indications from stream sampling results that further investigation may be warranted.

Palladium, Ni and Co concentrations in a B-horizon till sample (Tib-Soil-1026) were also anomalous at the same locality where anomalous values in Cu, Ni and Cr content were obtained from the C-horizon till sample. In the Tib Lake study area, B-horizon till and humus sampling is not as useful as sampling C-horizon till for mineral prospecting. The extensive areas covered by a surface layer of postglacial sand make collecting B-horizon till samples impossible for much of the area.

The results from several types of surficial media (peat, bog waters, stream sediments) display good contrast between sites underlain by the Tib Lake intrusion and granitic rocks. A further increased response near Cu-Ni-PGE mineralization demonstrates that both hydromorphic and clastic dispersion is occurring and can be used effectively to vector to mineralization. As mentioned above, the results near the Kuhner occurrence complement the till geochemical results in vectoring to the area northeast of the Kuhner occurrence as a possible source area for undetected mineralization (Figure 28). The results of stream sediment sampling also indicate potential for mineralization at the north end (Upper Border zone) of the Tib Lake intrusion.

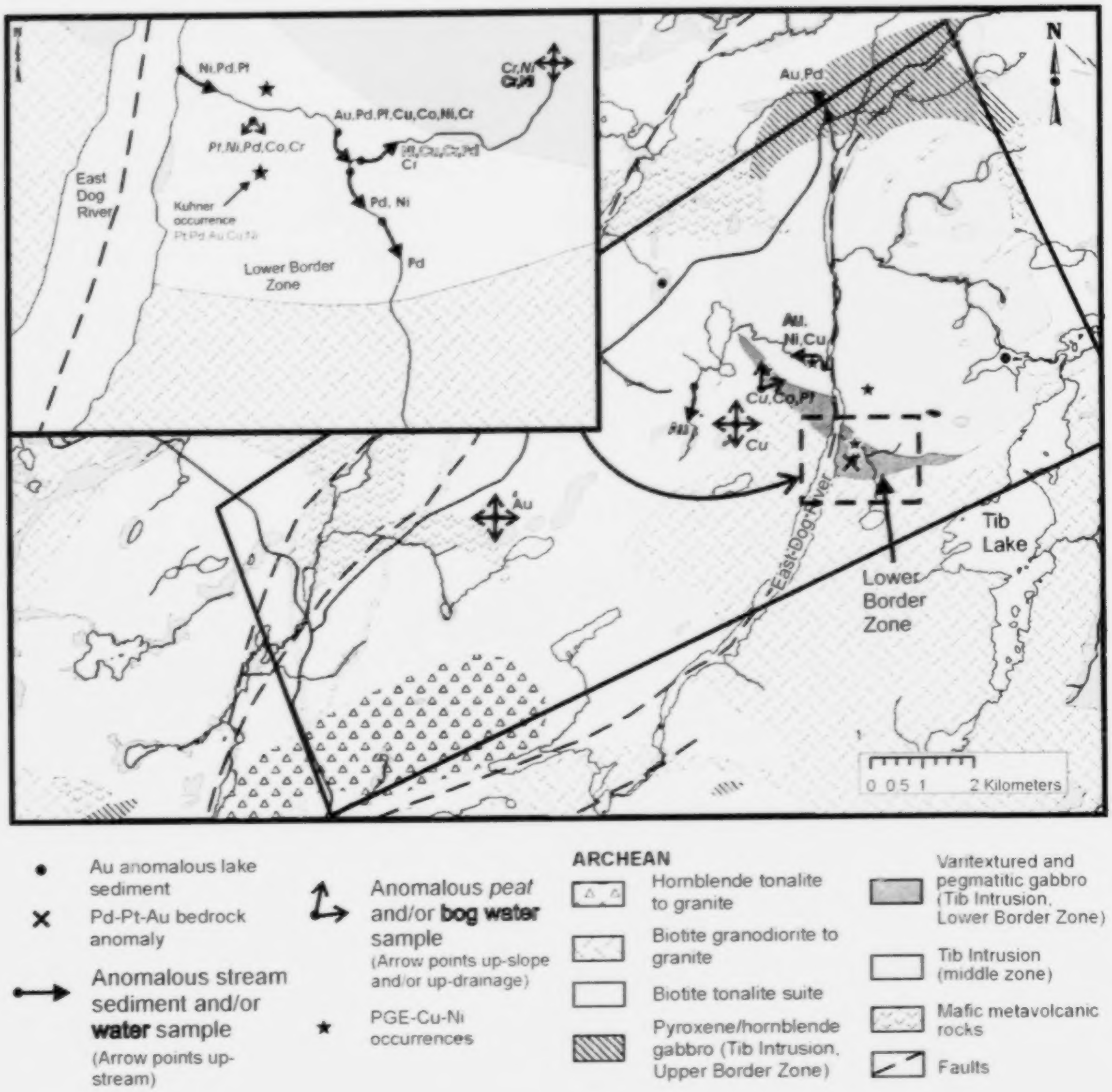
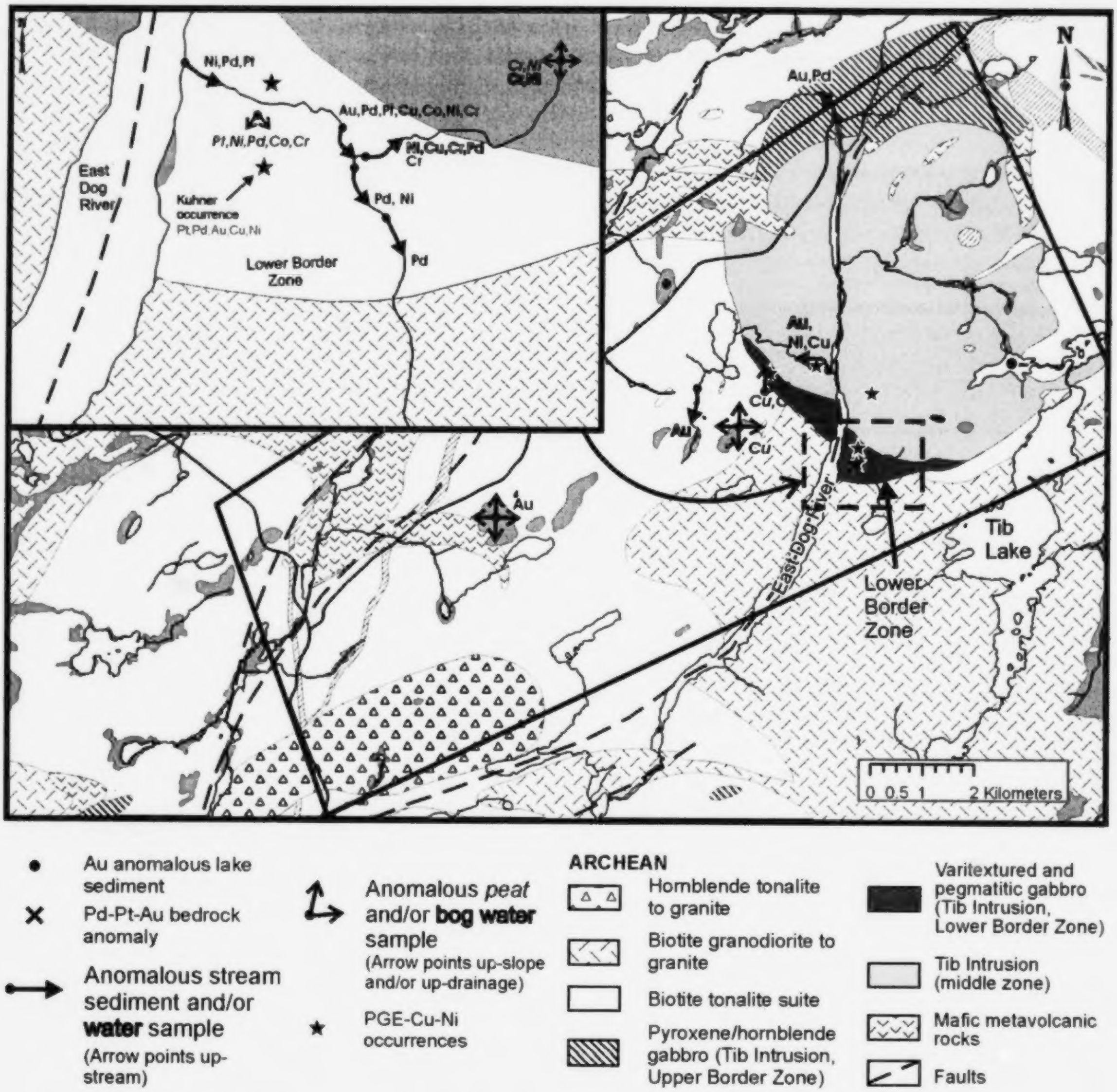

N
Ni,Pd,Pt
Cr,Ni Cu,Pt
Au,Pd,Pt,Cu,Co,Ni,Cr
Pt,Ni,Pd,Co,Cr
Ni,Cu,Cr,Pd Cr
East Dog River
Kuhner occurrence Pt,Pd,Au,Cu,Ni
Pd, Ni
Pd
Lower Border Zone
Au,Pd
Au, Ni,Cu
Cu,Co,Pt
Cu
Au
East Dog River
Tib Lake
Lower Border Zone
0 0.5 1 2 Kilometers
Au anomalous lake sediment
Pd-Pt-Au bedrock anomaly
Anomalous stream sediment and/or water sample
(Arrow points up-stream)
Anomalous peat and/or bog water sample
(Arrow points up-slope and/or up-drainage)
PGE-Cu-Ni occurrences
ARCHEAN
Hornblende tonalite to granite
Biotite granodiorite to granite
Biotite tonalite suite
Pyroxene/hornblende gabbro (Tib Intrusion, Upper Border Zone)
Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (middle zone)
Mafic metavolcanic rocks
Faults

Figure 28. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, peat and stream sediment, Tib Lake study area.


East Dog River
Ni,Pd,Pt
Pt,Ni,Pd,Co,Cr
Au,Pd,Pt,Cu,Co,Ni,Cr
Cr,Ni
Ni,Cu,Cr,Pd
Cr
Kuhner occurrence
Pt,Pd,Au,Cu,Ni
Pd, Ni
Pd
Lower Border Zone
N
Au,Pd
Au,
Ni,Cu
Cu,C
Au
Cu
Au
East Dog River
Tib Lake
Lower Border Zone
0 0.5 1 2 Kilometers
Au anomalous lake sediment
Pd-Pt-Au bedrock anomaly
Anomalous stream sediment and/or water sample
(Arrow points up-stream)
Anomalous peat and/or bog water sample
(Arrow points up-slope and/or up-drainage)
PGE-Cu-Ni occurrences
ARCHEAN
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Varitextured and pegmatitic gabbro (Tib Intrusion, Lower Border Zone)
Tib Intrusion (middle zone)
Mafic metavolcanic rocks
Faults

Figure 28. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, peat and stream sediment, Tib Lake study area.

CHEESEMAN LAKE STUDY AREA

Introduction

The Cheeseman Lake study area is a bedrock-controlled plateau underlain primarily by sills of diabase (Map 3, back pocket). It rises to over 100 m above the surrounding lowland areas. The surface of the plateau contains numerous depressions of various sizes that are commonly filled with lakes. The lakes are rimmed by a series of bedrock-controlled steps or escarpments. The surface of the plateau is also cut by curvilinear to linear valleys likely controlled by fracture systems developed in the sills. Areas of highly weathered sill rocks, weathered to depths exceeding 3 m, tend to occur along valley edges and rounded corestones floor the valleys. These relations suggest that deeper weathering has occurred along fractures in the sills and that subsequent removal of the less cohesive weathered rock (residual soil) has produced the valleys.

The overall irregular surface of the diabase sills in the Cheeseman Lake study area is similar to that of the Channelled Scablands of eastern Washington State (Baker et al. 1987). The only difference is that, here, the surface has been streamlined and till overlies the sculpted bedrock surface. This would suggest that the steep-walled valleys that occur throughout the case study area are possibly tunnel valleys that were carved by large discharges (floods) of meltwater flowing beneath the glacier.

Direction of ice flow across the area as indicated by glacial striae is varied. There is a radial pattern of striae from 290° immediately north of the study area to 255° in the south. At one site, striae oriented 190° were observed, but their age relationship to the radiating set could not be determined. Till associated with the radiating ice flow is widespread, but occurs commonly as a very thin discontinuous layer over the bedrock surface. It is a stony, silty-sand to sand till. Grain size analysis of 11 samples of till matrix (C-horizon) averaged approximately 62% sand, 35% silt and 3% clay-size particles. The matrix is low in carbonate, however, clasts of the Sibley Group were commonly observed in test pits.

Stratified ice-contact sand and gravel occurs in sinuous esker ridges and minor moraines in the southern part of the Cheeseman Lake area. A body of ice-contact sand that has been modified by wind occurs along the western border. Sand of glaciolacustrine origin occurs beneath the low-level plains that surround Cheeseman Lake.

Humus was thick enough (up to 10 cm) for sampling at most sites. Common soil horizons observed include Bf, Bm, BC and C. The Ae horizon was rare and, where present, very thin. Tops of the C-horizon generally occur 50 to 60 cm below the surface. Grain size analysis of 12 B-horizon till samples averaged approximately 41% sand, 55% silt and 4% clay, an increase of about 21% of these fine-grained components compared to C-horizon till samples. This is due to the breakdown and relocation of particles of the original parent material by soil forming processes.

In the area north of Cheeseman Lake, till commonly forms only a veneer over the bedrock surface on top of the plateau and tends to be thicker along plateau slopes. On the plateau tops, B-horizon soils are commonly developed in bedrock (residual soil), not till, and the Type 5, "geogenic", soil geochemical soil profile type of Klassen (2003) occurs. At several sites, the till cover over bedrock was too thin to collect B- and/or C-horizon till samples. At these sites, the weathered bedrock or residual soil was noted and sampled. B- and C-horizon samples of both till and residual soil were collected during this study, however, consideration of this was taken during the interpretation of geochemical results for B- and C-horizon samples.

The development and preservation of residual soils is not uncommon in areas underlain by mafic to ultramafic rocks and, in particular, the Nipigon diabase sills. Areas of deep (>3 m) residual soils occur in the down ice-flow protected side of rock knobs and ridges indicating that the weathering processes may have operated prior to the last glacial event. However, large rotted boulders in till and glaciofluvial gravel and sand deposits, and weathered bedrock beneath till in unprotected areas, such as plateau surfaces, indicate that the disintegration and weathering of the bedrock are also postglacial and ongoing processes.

The Nipigon diabase sills are composed of medium- to coarse-crystalline feldspar and pyroxene that should properly be classified as gabbro (Hart and Whaley 2004). Gabbro is approximately 10 times greater than diabase with respect to water absorption (Kazi and Al-Mansour 1980) and "rocks with high absorption values will be more susceptible to both physical and chemical weathering" (Gerrard 1988, p.90). The coarse-textured nature of the sills, the extensive joints and fractures combined with the mineralogy and water absorption characteristics support both physical and chemical weathering processes. Deep weathering occurs downward from the surface and along fractures and joints producing a granular residual soil with the development of corestones near the base of the weathering front. Grain size analysis of 4 samples of residual soil (C-horizon) averages approximately 92% sand and 8% silt-size particles. The granular nature of the residual soil developed in the Nipigon sills promotes water movement through the soil (relatively high permeability), greater mineral–water interactions and deeper soil development (enhanced soil-forming processes) within the bedrock.

The results of deeper soil development in these rocks are displayed by the occurrence of loose granular gabbroic sand (residual soil) along fractures and joints adjacent to competent gabbro at depth and valley bottoms littered by rounded corestones. Along these valleys, the granular residual soil has been removed by stream erosion leaving the larger corestones behind, particularly in the Cheeseman Lake study area. Surface and groundwater has transported minerals and rock fragments downstream to be deposited as stream or lake sediment. Elements, such as Pd and Cu and, to a lesser extent, Pt and Ni, likely move in solution as well and potentially affect levels of these elements in both stream and lake water.

Till: Glacial Dispersal

Till can be used in the Cheeseman Lake study area for mineral exploration, however, locating C-horizon till samples can be difficult. The main reasons for this are that, in some areas, the till can be very thin and discontinuous. In these areas, soil-forming processes have affected the entire thickness of the till making the collection of C-horizon samples impossible. However, geochemical results from the C-horizon till samples collected are of interest despite the factors affecting their spatial distribution.

HEAVY MINERAL RESULTS

Six samples from the Cheeseman Lake study area were processed by GeoLabs and underwent heavy mineral analysis to obtain the overall heavy mineral assemblage in till from this area. The average heavy mineral composition consists of approximately 69% clinopyroxene, 10% calcic amphibole, 7% orthopyroxene, 4% ilmenite, 2.7% sub-calcic amphibole and minor amounts (<2%) of fayalite, forsterite, epidote, chlorite, titanite and apatite. These minor constituents can be of interest in mineral exploration (Averill 2001).

In addition, 6 heavy mineral samples, 5 till and 1 stream sediment, were processed and analyzed by Overburden Drilling Management Limited (ODM) of Nepean, Ontario. The reports provided by ODM concentrate on the important minor constituents or indicators of mineralization of the heavy mineral assemblages. The results provided by ODM are contained in MRD 154.

Overburden Drilling Management Limited recognized several mineral assemblages within the Cheeseman Lake set of samples. Pigeonite dominated the assemblages that also included diopside, titanite and/or epidote.

No mineral grains containing platinum or palladium were recovered from the 6 samples collected in the Cheeseman Lake area. Gold grains were recovered from 4 of the 6 samples: 3 grains from 03-PJB-024 (1 pristine), 1 pristine grain from 03-PJB-009, 1 reshaped grain from 03-PJB-195 and 1 pristine grain from 03-PJB-062 (alluvial sediment). There were no kimberlite indicator minerals reported from the Cheeseman Lake area samples. Very few other indicator minerals were recovered. A till sample (03-PJB-009) collected 1.6 km north of Danby Lake contained 8% fayalite grains, 2 coloured spinels and 1 grain of kyanite. Sample 03-PJB-024 contained 5% fayalite and 1 grain of red rutile and sillimanite; sample 03-PJB-040 has 4% fayalite; and stream sediment sample 03-PJB-062 contained 4% fayalite. Sample 03-PJB-195 contained 2% fayalite, 2 low-Cr diopside grains and 1 grain of red rutile.

C-HORIZON TILL SAMPLE GEOCHEMICAL RESULTS

C-horizon till is material that was deposited directly from the glacier with little to no alteration as a result of soil-forming processes or weathering. Samples of till indicate the physical dispersal of rock fragments and minerals from bedrock sources by glaciers in the down glacier ice-flow direction. Sampling density in the Cheeseman Lake study area was not sufficient to delineate discrete dispersal trains associated with mineralization, however, the distribution and values obtained from the geochemical analysis of the samples collected are of interest for several elements. In C-horizon till samples, Pd, Au, Cu, Ni, Co and Zn have similar spatial patterns (Figure 29). The spatial distribution of Pt varies slightly from that of Pd, in that it contains an additional elevated value south of Cheeseman Lake.

The results discussed below are based on fire assay and ICP for PGEs and ICP for the other trace elements. A summary of the results is presented in Table 5. Results for all geochemical analyses performed are contained in MRD 154.

Platinum Group Elements

Two C-horizon till samples (Che-Soil-2006 and Che-Soil-2014) collected in the Cheeseman Lake study area contain anomalous Pt. Both samples are regional till samples located a short distance beyond the anomalous catchment basin study areas.

Two till samples were also anomalous with respect to Pd (Che-Soil-2019 and Che-Soil-2022). They both occur within the anomalous catchment basin area 1 (*see* Figures 29 and 32). Palladium values were 8.8 and 8.9 ppb, respectively. An anomalous Au value (6.7 ppb) was also obtained from sample Che-Soil-2022 from this catchment basin.

Associated Elements

Broad, regional, dispersal trains for several trace elements that are commonly associated with Pt and Pd occur in the Cheeseman Lake study area. The distribution of Cu, Ni, Co and Zn in C-horizon till samples are similar. Elevated concentrations for these trace elements occur within anomalous catchment basin area 1 (*see* Figures 29 and 32) based on contouring of trace element concentration distributions using inverse distance weighting techniques. Anomalous values in Cu, Ni, Co and Zn content were obtained in C-horizon till samples collected within this catchment basin (anomalous catchment basin area 1). Anomalous values of Mg and Cr occur about 5 km east-northeast of Danby Lake, however, unlike the Lac des Iles study area, the concentrations of PGEs are fairly low in this sample.

Till: Soil Profile Geochemistry

Following deglaciation, the materials making up the land surface were exposed to weathering and soil-forming processes. The parent material (C-horizon) of the soil began to alter physically and chemically in response to these processes and other soil horizons formed. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter), was also sampled during this project.

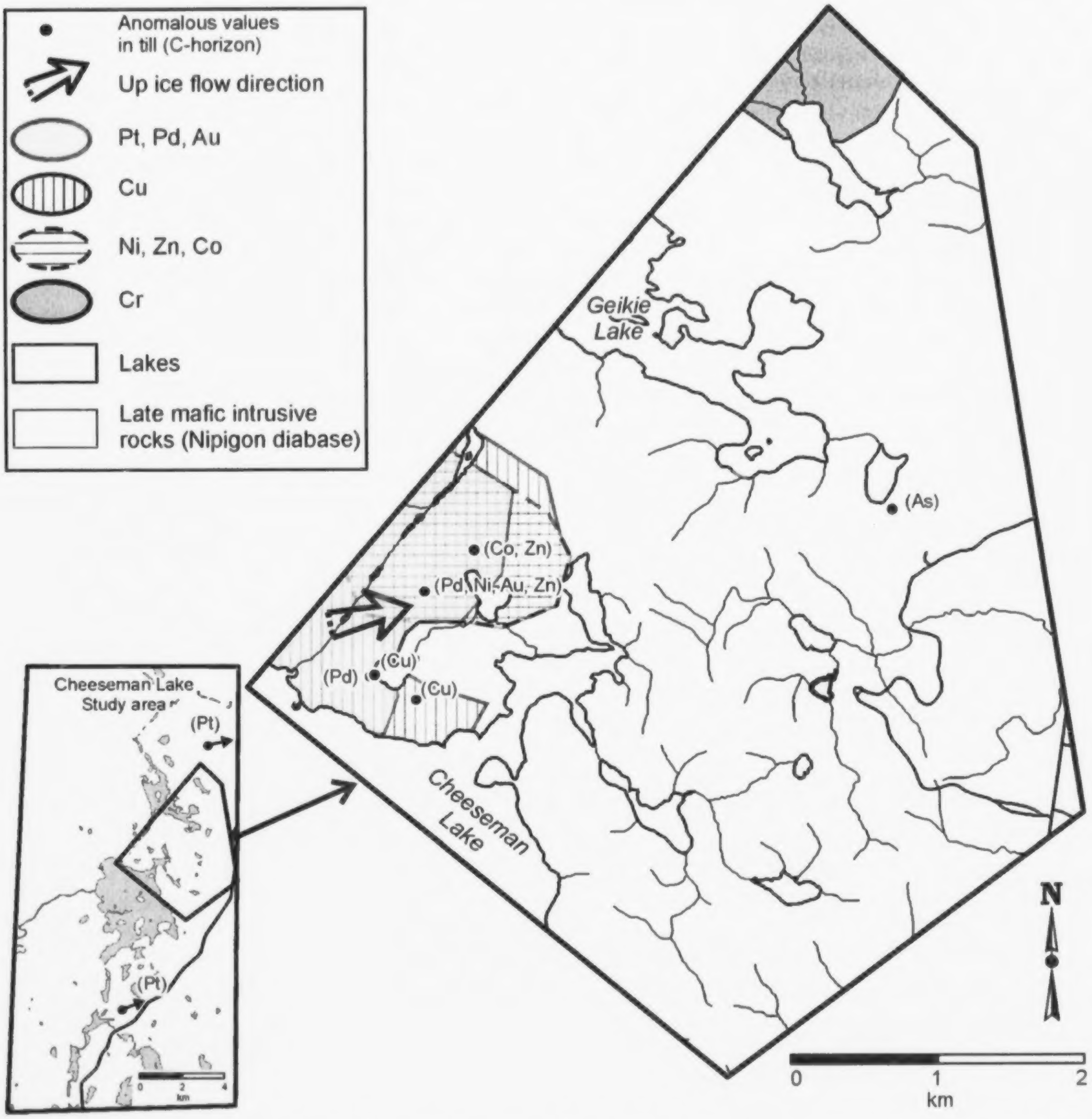


Figure 29. Distribution of anomalous ($\bar{x}+2\sigma$) samples and areas of regionally elevated PGE and associated elements from C-horizon till samples, Cheeseman Lake study area. Elements in brackets are anomalous values in individual till samples and element assemblages not in brackets are related to areas of elevated concentrations.

In all the case study areas that have soils developed entirely in till, there is generally a decline in concentration of Pt, Pd, Ni, Cu, and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching"-, profile, that is, a net downward increase in element concentration (*see* Figure 7), of the 5 basic geochemical profile types proposed by Klassen (2003). However, many sites, particularly those on plateau surfaces in the Cheeseman Lake study area, have Type 5, "geogenic", profiles, that is, different materials, stratigraphy, within the soil profile or a change in parent material through the soil profile (Klassen 2003; *see* Figure 7). At these sites, there is also a chemical disjunct between the thin layer of till at surface and the weathered bedrock or residual soil making up the mineral soil layers at depth. In this case study area, where it was important to determine the contribution of each media to lake sediment geochemical anomalies within the catchment basin lakes (Dyer and Russell 2002), humus, B- and C-horizon samples were collected regardless of the origin of the parent material. As a result, only a few B- and C-horizon till samples and samples of humus formed over complete soils developed in till could be collected and analyzed.

Sites that did contain B- and C- horizon mineral soil horizons developed in till, commonly fall into the Type 1, "leaching", profile, that is, a net downward increase in element concentration for Pt, Pd, Ni, Cu, Cr and Co (Klassen 2003). Variations in Pt and Pd concentration between the various soil horizons at many sites were less than the error of laboratory measurements; however, the general decrease in concentration up soil profile trend remains.

Gold and Zn commonly illustrate the Type 2, "accumulation (surface)", geochemical profile type in soil profiles developed in till from the case study area (Klassen 2003; *see* Figure 7). For these elements, however, biological processes are the preferred mechanism of enrichment in humus samples.

The soil profile geochemistry of Pt is similar to that of Pd. In general, Pt concentrations are less than Pd and the mobility or degree of decrease in concentration up the soil profile is less than Pd. Copper behaves similar to Pd being very mobile in soils in the Cheeseman Lake study area. It is not uncommon to observe a 50% reduction in Cu content from C-horizon to B-horizon samples. There is a general trend for the concentration of Ni to decrease up through the soil profiles developed in till. There is not as much removal of Ni as occurs with Cu in the B-horizon, that is, the geochemical gradient or mobility is not as great for Ni as Cu in soil developed under Cheeseman Lake area climatic conditions. Results of the analysis of B-horizon and humus samples are contained in MRD 154.

Platinum was anomalous in 2 B-horizon samples: Che-Soil-2001 and Che-Soil-2035. Both these samples were at the toe of steep slopes developed in bedrock where downslope movement of ground water may have transported and concentrated Pt in these locations. Sample Che-Soil-2001 is located in the "background lake", Danby Lake catchment basin, and Che-Soil-2035 is in "anomalous catchment basin 3".

Palladium is anomalous in a B-horizon till sample (Che-Soil-2009) in "anomalous catchment basin 2" probably due to similar downslope concentration. There is also enrichment in the concentration in Cu in the B-horizon compared to the C-horizon sample at this location. The higher concentrations may be the result of the weathering and dissolution of bedrock upslope in these cases. The overall concentration of most of the elements discussed herein (except Ni and Cr) is several times higher in bedrock or residual soil samples than the till samples collected in the Cheeseman Lake study area.

Copper concentrations were locally anomalous in B-horizon till samples, for example, Che-Soil-1003 within the Danby Lake catchment basin and Che-Soil-1016 in "anomalous catchment basin 1", where an anomalous value of Cu was obtained from the corresponding C-horizon sample. Nickel was locally anomalous along the southern edge of "anomalous catchment basin 3" (Che-Soil-1034 and Che-Soil-1035).

Table 7. Geochemical results for selected elements in residual soil samples (B-, BC- and C-horizon) from the Cheeseman Lake and Circle Lake study areas.

	Pd (ppb)	Pt (ppb)	Au (ppb)	Ni (ppm)	Cu (ppm)	Cr (ppm)	Co (ppm)	Zn (ppm)	Mg (%)	Fe (%)
Cheeseman Lake (n=6)										
mean	30.1	7.1	13.0	28.6	951.7	15.4	37.0	149.5	0.8	9.4
standard deviation	67.7	24.4	49.3	11.4	774.5	4.8	20.3	58.8	0.4	4.6
Circle Lake (n=28)										
mean	7.4	9.0	3.7	46.5	314.6	13.6	33.7	129.1	0.8	6.5
standard deviation	6.5	7.7	3.4	65.3	260.2	6.3	17.8	70.6	0.9	2.0
all samples (n=34)										
mean	9.5	8.6	4.6	42.1	383.3	14.5	33.3	126.8	0.8	6.7
standard deviation	31.7	11.8	22.1	59.6	475.8	6.9	18.0	69.0	0.9	3.0

Residual Soil: Soil Profile Geochemistry

Soils are also developed in bedrock or areas where there is a thin cover of till overlying the bedrock in the Cheeseman Lake study area. In soils developed entirely in bedrock, there is generally a decline in concentrations of Pt, Pd, Ni, Cu and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (Klassen 2003; *see* Figure 7). In the composite thin till over bedrock settings, a Type 5, "geogenic", geochemical soil profile occurs (Klassen 2003; *see* Figure 7). However, as a result of the large difference between the initial trace element concentrations in the bedrock and that in the till, there is a decline in concentrations of Pt, Pd, Ni, Cu and Cr up through the soil profile (Type 1: Klassen 2003). There are also major decreases in Pt, Pd and Au concentrations from B-horizon samples developed in residual soil and corresponding humus samples. A summary of the results of analysis of residual soil samples from the Cheeseman Lake and Circle Lake areas is presented in Table 7.

RESULTS OF HUMUS SAMPLING

Concentrations of most elements examined are generally lower in humus samples collected from the Cheeseman Lake study area; the concentrations of Au and Zn being the exceptions where the soil is developed in till. Copper and Pd reach anomalous ($\bar{x}+2\sigma$) values in humus (sample Che-Soil-0032) within anomalous catchment basin 3. The humus has developed over a thin layer of till resting on bedrock. Concentrations, particularly of Cu, are much greater than in the corresponding B-horizon sample. Downslope movement of trace elements in groundwater from bedrock-controlled ridges combined with organic fixing may explain the anomalous Cu and Pd concentrations found in humus at this site.

Lake Sediments

The Cheeseman Lake study area was specifically targeted for lake sediment sampling by the OGS in 1998 during the Garden Lake–Obonga Lake area lake sediment survey. This was due to the presence of anomalous levels of Au (9 and 13 ppb) and Cu (820 and 1080 ppm) in 2 lakes determined by the National Geochemical Reconnaissance (NGR) program and published in 1990 (Friske, McCurdy and Cook 1990). The 2 lakes in question (OGS sites 2050 and 2055: Jackson and Dyer 2000), located to the northeast of

Cheeseman Lake, returned very similar results from the 1998 OGS survey (6 and 9 ppb Au; 935 and 928 ppm Cu). Resampling of these 2 lakes again in 2001 (OGS sites 1265 and 1270: Dyer and Russell 2002) once again corroborated the presence of anomalous Au (6.7 ppb and 11 ppb) and Cu (812 ppm and 719 ppm). The 1998 survey also targeted 18 additional lakes in and around the original anomalous lake sites, of which 11 returned anomalous Au (up to 13 ppb) and 16 returned anomalous Cu (up to 1255 ppm). During the 2001 survey, 17 of these 18 lake sites were resampled, resulting in Au anomalies at 13 sites (up to 46 ppb) and Cu anomalies at 11 sites (up to 943 ppm). Most of these anomalous lakes are within the drainage catchments targeted by the present study. The only additional lake sediment sampling under this LNRGI project was from the northern part of Cheeseman Lake, where previous attempts had failed to obtain a sample, presumably due to a hard or sandy lake bottom. Three sample sites on Cheeseman Lake were attempted under this project, of which 2 obtained a sediment sample. No significant base or precious metal values were obtained.

Lithogeochemistry

A total of 28 rock samples were collected in this case study area. At least 3 bedrock samples were collected from around each lake within each drainage catchment investigated. Almost all were field identified as medium- to coarse-grained diabase with varying degrees of weathering. Subsequent examination of the lithogeochemical data, including REE plots (e.g., Gd/Yb versus La/Sm, Figure 30) confirmed that all are diabase of the Nipigon sills. Richardson and Hollings (2004) suggest that the Nipigon Embayment may have as many as 5 geochemically distinct suites of sills. These 5 possible

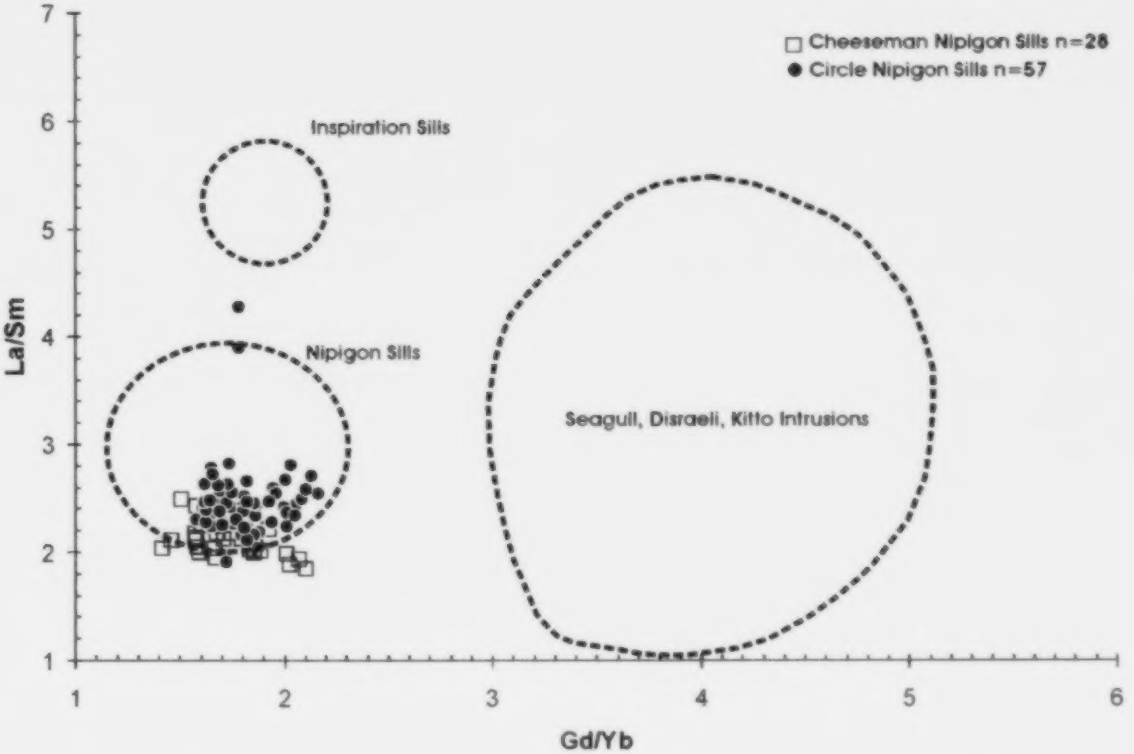


Figure 30. Gd/Yb versus La/Sm diagram for rock samples collected in the Cheeseman Lake and Circle Lake study areas.

suites are shown in Figure 31 (Zr/Y versus Mg#) and show that the Cheeseman Lake area diabase samples overlap the lower part of the Main Nipigon suite field (magnesium numbers ranging from 0.12 to 0.41). Mean levels of the metals of economic interest are as follows: Pd = 30.3 ppb; Pt = 3.8 ppb; Au = 6.2 ppb; Ni = 57.8 ppm; and Cu = 266.8 ppm. Over 50% of the diabase samples collected within the anomalous catchments were described as coarse grained and strongly weathered (iron stained and/or hematite altered).

The precious metals, Pd (Figure 32), Pt and Au, are elevated relatively in bedrock within "anomalous" catchment 3 compared to the rest of the sampled catchments. Precious metal levels in diabase sampled within catchments 1 and 2 are not significantly different than the background catchment at Danby Lake. Copper is elevated in catchment 3, but one of the highest Cu values in the study area also came from the Danby Lake area. The concentrations of Co, Cr and Ni in bedrock display no significant zonation or pattern across the study area, with the exception that the 2 highest values for each of these elements came from 2 sites within the Danby Lake background catchment. Five bedrock samples were collected in the Danby Lake catchment; REE results suggest that the diabase sampled in this area is somewhat geochemically distinct compared to the diabase within the anomalous catchments. The Gd/Yb ratios are the highest of all the Cheeseman Lake area rocks sampled and the La/Sm ratios are among the lowest. Considering the lower elevation (average differentially corrected GPS elevation of 406 m asl) of the bedrock sample sites in this catchment area, compared to the other targeted catchments (most sites at elevation >415 m asl, average of 424 m asl), it is possible that a lower level of the sill was sampled. Detailed sampling of Nipigon diabase sills from drill core has shown that significant vertical geochemical variation does occur (Hart and Magyarosi 2004; T.R. Hart, OGS, personal communication, 2005).

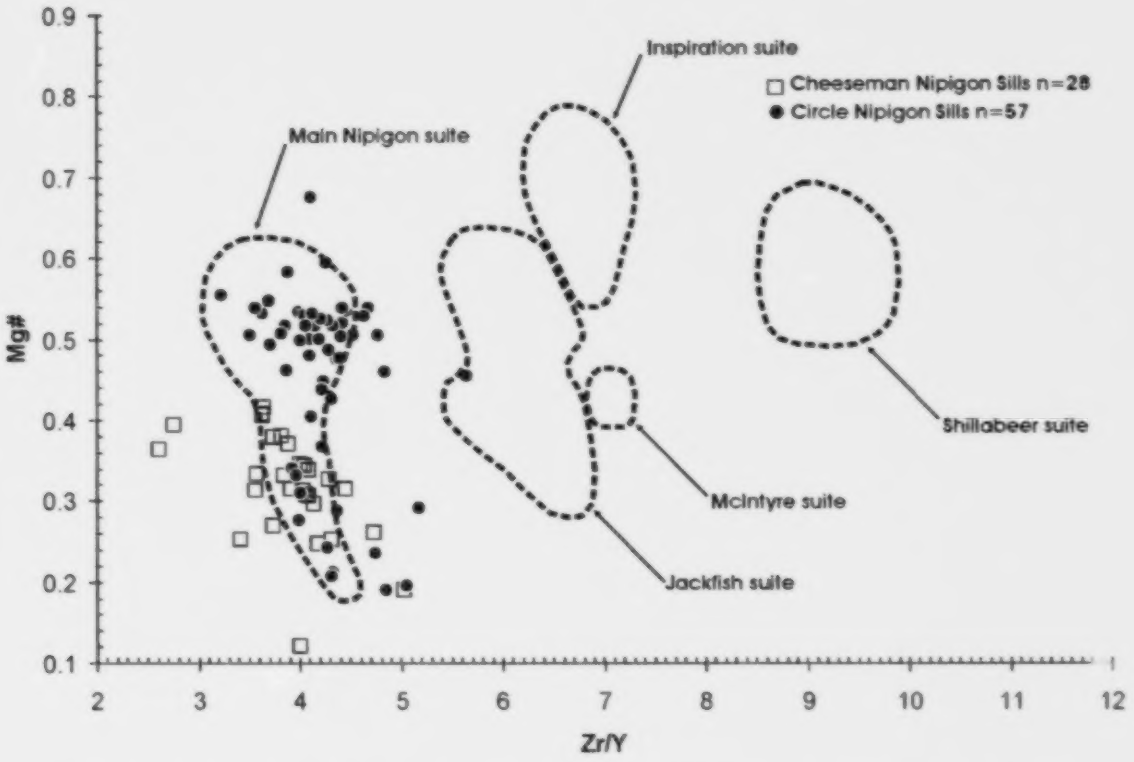


Figure 31. Zr/Y versus Mg# diagram for rock samples collected in the Cheeseman Lake and Circle Lake study areas.

Hydrogeochemistry

Surface water (stream water, lake water and springs) pH within the sampled drainage catchments is approximately neutral averaging between 6.8 and 7.0. The pH of shallow bog waters is significantly more acidic, averaging 5.6. This acidity likely reflects the presence of natural organic acids. In general, the neutral to slightly acidic pH conditions across the study area are conducive to hydromorphic transport of metals.

Conductivity of all waters indicates a general higher level of total dissolved solids in the northern portion of the study area (anomalous watershed 3 and northward). Higher levels of the major elements, such as Ca, are present in the waters of "anomalous watershed 2" and the Danby Lake area, although pH levels are not significantly different than in the south. Calcium levels in bedrock show no corresponding enrichment; it is likely that this is related to the presence of thicker, more continuous Quaternary deposits and consequent higher major element loadings to the streams and lakes.

LAKE WATERS

A total of 10 lake waters were collected within the Cheeseman Lake study area. The average (9.3 ppb) and median (7.9 ppb) levels of Cu are the highest of the 5 case study areas. Three lakes within catchment 3 had the highest Cu levels of 9.5 ppb, 11.9 ppb and 18.5 ppb (Figure 33). Lakes in the other 2

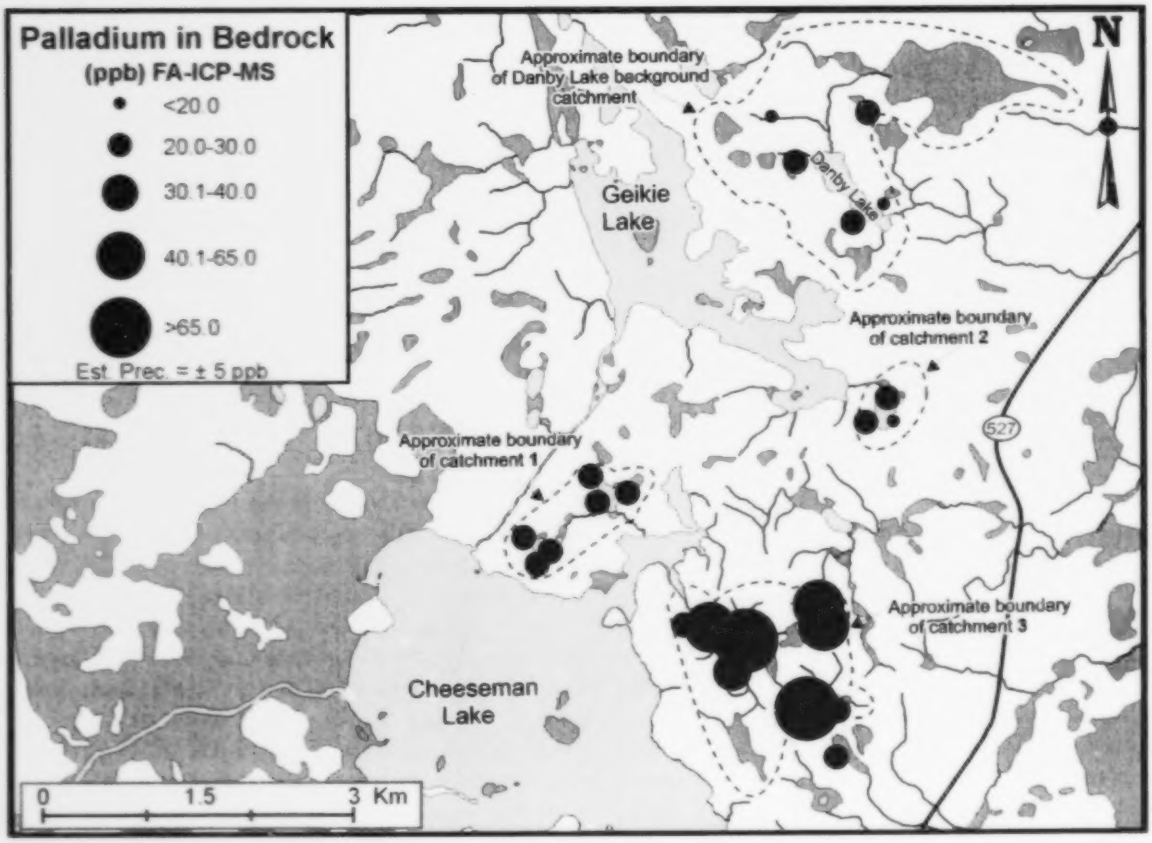

Palladium in Bedrock
(ppb) FA-ICP-MS
<20.0
20.0-30.0
30.1-40.0
40.1-65.0
>65.0
Est. Prec. = ± 5 ppb
N
Approximate boundary of Danby Lake background catchment
Geikie Lake
Danby Lake
Approximate boundary of catchment 2
527
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cheeseman Lake
0
1.5
3 Km

Figure 32. Palladium in bedrock, Cheeseman Lake study area.

"anomalous catchments" had Cu levels of 7 to 8 ppb. The background lake (Danby Lake) had a value of 3 ppb Cu at its outlet creek. The levels of Ni, Co, Pd and Pt were too low to be significant compared to their estimates of precision; the levels of Cr and Au were almost all below detection limit.

STREAM WATERS

The highest levels of Cu in stream water occur in catchments 2 and 3. Each of these catchments had one creek that returned over 37 ppb Cu. In catchment 3, this anomalous Cu result came from a stream draining the north shore of the most southeasterly lake. The most significant Ni (2.5 ppb) and Pd (3.0 ppt) values came from catchment 2. Four samples in catchment 3 returned Pd levels greater than 1 ppt; these are along the north shore and outlet creek of the southeastern lake. Cobalt levels are clearly the highest in several streams of catchment 3. The highest Au level (2.6 ppt) came from catchment 1. Platinum levels are low; the highest value of 0.21 ppt came from catchment 3. These results contrast with relatively low Au, Co, Cu (<4 ppb), Pd (<1 ppt) and Pt (<0.1 ppt) levels that characterize most of the inlet streams at Danby Lake (background catchment).

SHALLOW GROUNDWATER

A total of 26 samples of water were collected from bog sumps, 11 samples from natural springs and 2 samples from the bottom of soil pits. Bog waters were plotted and interpreted separately from the spring and soil pit waters; the spring and soil pit waters were combined for plotting purposes and in this

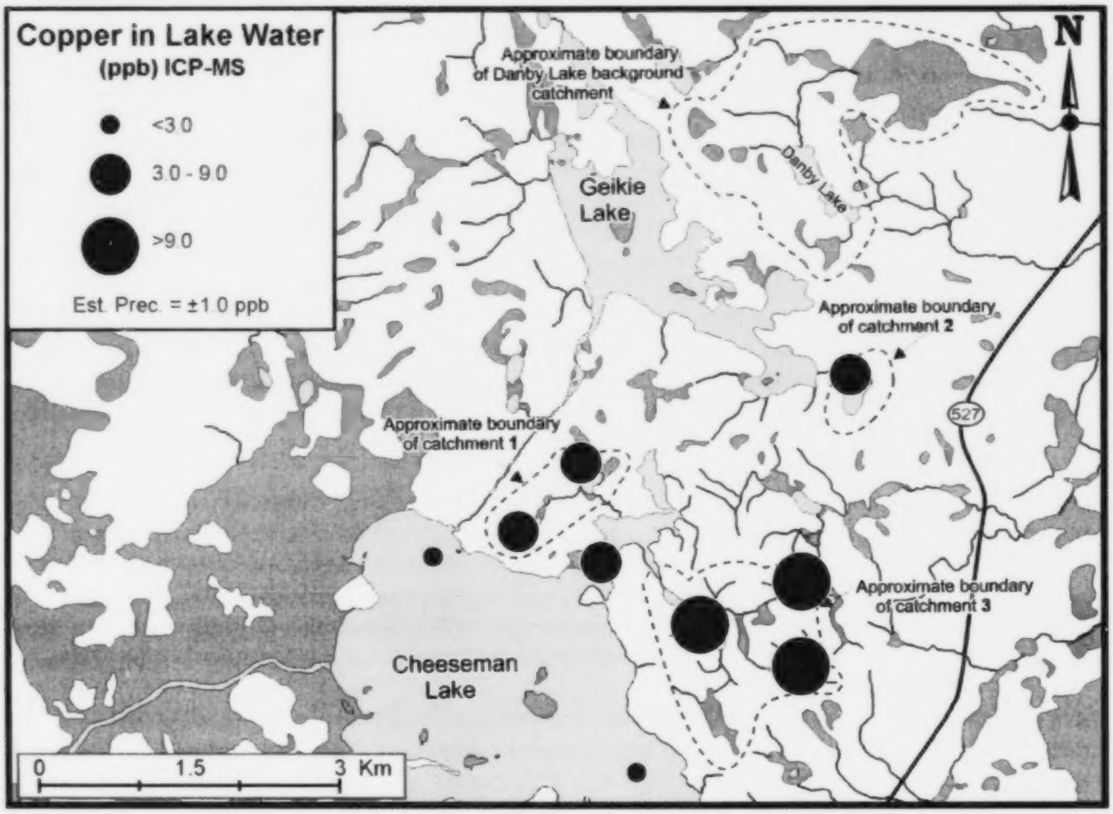

Copper in Lake Water
(ppb) ICP-MS
● <3.0
● 3.0 - 9.0
● >9.0
Est. Prec. = ±1.0 ppb
N
Approximate boundary of Danby Lake background catchment
Geikie Lake
Danby Lake
Approximate boundary of catchment 2
527
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cheeseman Lake
0
1.5
3 Km

Figure 33. Copper in lake water, Cheeseman Lake study area.

discussion are termed groundwaters. Copper results for bog water (Figure 34) and groundwaters display a clear pattern of higher background within each of the targeted anomalous drainage catchments compared to the background (Danby Lake) catchment. The highest levels of Cu came from the springs and the 2 soil pits, with the exception of one highly anomalous value (148 ppb) from a bog water (sump) in catchment 3 on the north shore of the southeastern lake. The 3 highest levels of Co came from catchments 1 and 3. Two of these occur in catchment 3, along the north shore of the southeastern lake (1 bog water and 1 spring water). Outside of these 3 sites, Co levels are similar to those found at the background catchment at Danby Lake.

Nickel displays a weak pattern of higher levels within drainage catchments 1 and 3. Chromium results are mostly below detection limit, but the single highest value (8.3 ppb) came from the north shore of the southeastern lake in catchment 3.

Overall, Pd levels are weakly elevated within the anomalous catchments relative to the background catchment. The highest value for Pd (7 ppt) came from a sample (site CHE-BOG-15) along the north shore of the southeastern lake in catchment 3. The highest (anomalous) Au value (20.5 ppt) came from CHE-BOG-17 in drainage catchment 3. Otherwise, the Au levels in catchments 1 and 3 are clearly higher than at the background catchment. Platinum shows a weak pattern of higher levels within catchment 1, relative to the other anomalous catchments and the background catchment.

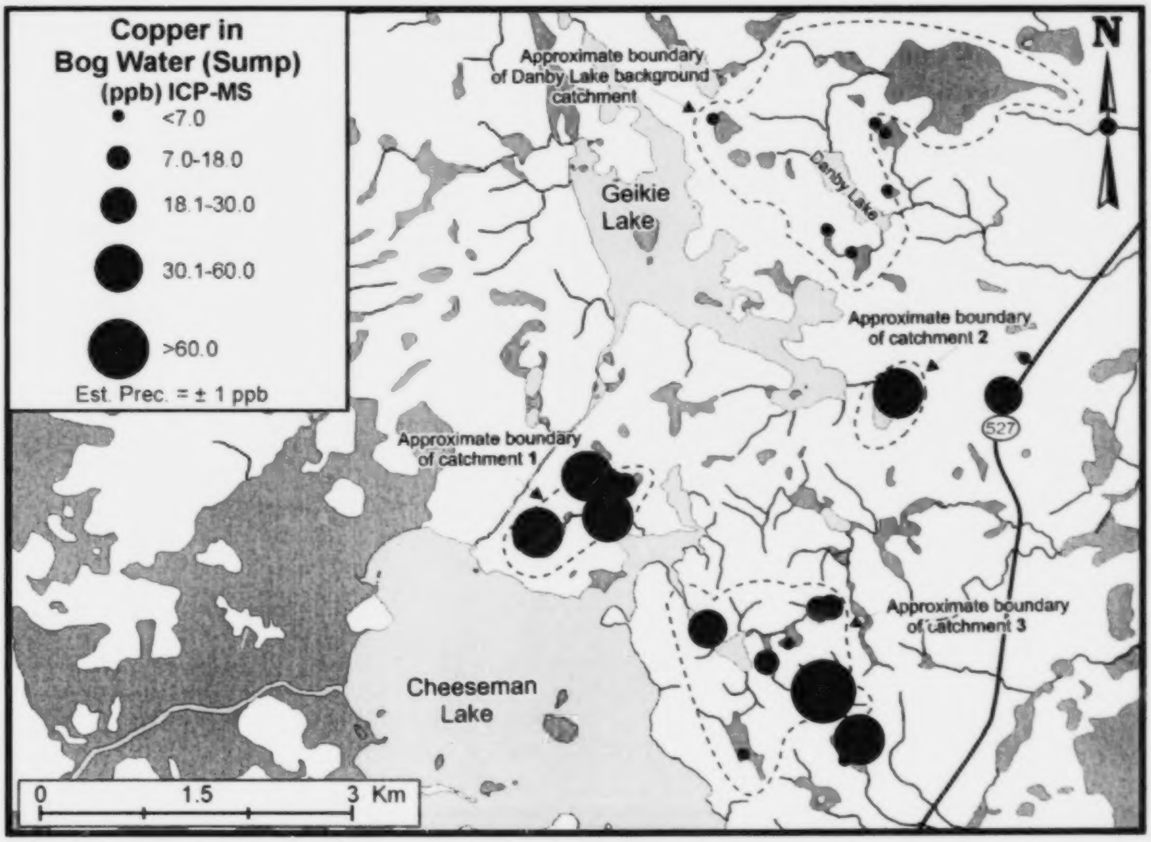

Copper in
Bog Water (Sump)
(ppb) ICP-MS
<7.0
7.0-18.0
18.1-30.0
30.1-60.0
>60.0
Est. Prec. = ± 1 ppb
N
Approximate boundary of Danby Lake background catchment
Danby Lake
Geikie Lake
Approximate boundary of catchment 2
527
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cheeseman Lake
0
1.5
3 Km

Figure 34. Copper in bog water, Cheeseman Lake study area.

Stream Sediments

A total of 9 inorganic stream sediments were collected, including 3 at Danby Lake and one at Cheeseman Creek where it intersects Highway 527. Copper levels in inorganic stream sediment in the Cheeseman Lake area are the highest of all the study areas. The highest (highly anomalous) Cu value (683 ppm) came from catchment 3 along the north shore of the southeastern lake. A value of 389 ppm Cu (second highest) was obtained at the outlet creek of the lake at catchment 2. A creek at the northwest end of Danby Lake returned a value of 216 ppm, the third highest. This correlates well with 2 bedrock samples northwest of Danby Lake that returned Cu levels of 216 and 436 ppm. Background levels of Cu (<45 ppm) were obtained at 2 creeks at the southeast end of Danby Lake (1 inlet and 1 outlet) and 2 samples on Cheeseman Creek.

Nickel and Cr in inorganic stream sediment are present at low levels in the Cheeseman Lake study area (average and median values lowest of all the case study areas). The 3 highest levels of these metals came from 3 separate and mutually distinct localities: 1) Cheeseman Creek (near Highway 527); 2) a small sandy creek near the drainage outlet of catchment 3; and 3) a small inlet creek to Danby Lake. The creek at Danby Lake is downstream of a bedrock sample site that returned a high (134 ppm) Ni value.

The highest levels of precious metals consistently came from 3 sample sites: 1) the highest Au (15.1 ppb by FA; 23.3 ppb by INAA) and Pd (74.6 ppb) from a sample along the north shore of the southeastern lake in catchment 3; 2) the outlet creek of the lake at catchment 2; and 3) a small inlet creek at the north end of Danby Lake. Gold results demonstrated good correlation between the INAA and FA–ICP–MS methods.

A total of 22 organic stream sediments were collected in the Cheeseman Lake study area. Nickel, Co and Cr are present at relatively low levels in the Cheeseman Lake area organic stream sediments compared to the other case study areas. Nickel and Cr display slightly higher levels in catchments 1 and 3 relative to the background catchment. Cobalt varies randomly in the samples obtained. Copper displays a strong spatial relationship with all 3 anomalous catchments; each has at least 1 stream sediment that returned over 600 ppm Cu. Three sites within anomalous catchment 3 returned values of greater than 500 ppm Cu. These 3 creeks vector to a source area north of the southeastern lake, as have various other sample results (discussed above). The precious metals Pd (Figure 35) and Au are consistently elevated to anomalous within catchments 1 and 3 compared to the background (Danby Lake) catchment.

Peat

Organic peat samples were collected from 23 sites. Of the base metals, Cu returned the best pattern in terms of contrast between the anomalous and background catchments. The highest Cu in peat value came from anomalous catchment 1. All of the peat samples in this catchment returned Cu values over 200 ppm and 2 samples over 950 ppm (overall average of 600 ppm). Catchment 2 had only 1 peat sample, but it returned a value of 704 ppm Cu. The peat in drainage catchment 3 returned an average Cu value of 360 ppm, with a high anomalous value of 862 ppm from CHE-BOG-18. Five of 6 samples in the background (Danby Lake) catchment returned less than 150 ppm Cu. The highest came from a site near the bedrock ridge that had returned a high Cu value discussed in "Lithogeochemistry" above. Copper by Enzyme Leach^{SM} returned anomalous levels in both catchments 1 and 3; the intensity of the anomalies being stronger in catchment 1. The disparity in Cu levels between catchments 1 and 3 may be due to the more rugged topography and slopes surrounding the lakes in catchment 1.

Nickel, Co and Cr values in peat are relatively low compared to the other study areas. Each of these elements returned a different pattern. The highest Ni (20 ppm) came from catchment 1; otherwise, Ni levels are not much different between the anomalous and background catchments. Chromium levels are distinctly elevated in catchment 1 and 2 compared to catchment 3 and the background catchment. Cobalt levels are consistently high in catchment 1, but the single highest value came from catchment 3; relatively low Co levels characterize the background catchment. Nickel and Co by Enzyme Leach^{SM} show a strong anomalous response in catchment 1, with good contrast compared to the background catchment.

Palladium concentrations in peat in the Danby Lake area range from <1 to 8 ppb (average 4 ppb) by fire assay. This contrasts with the anomalous catchments, which average 12 ppb (range of 1.5 to 40 ppb). The highest values of 26 ppb and 40 ppb came from catchments 2 and 3, respectively. Palladium levels outside of the background (Danby Lake) and targeted anomalous catchments (n=4) consistently returned approximately 8 ppb Pd. This level likely approximates the background level of Pd in the Cheeseman Lake study area. Results for Pd by the ashed-ICP method are significantly lower (average of <1 in Danby Lake area) and exhibit less contrast between background and anomalous areas, but display a similar overall pattern.

Platinum levels are low in the sampled peat, that is, there is no significant difference observed between background areas and the anomalous catchments. The only value (2 ppb by FA–ICP–MS) of possible significance came from CHE-BOG-18 in catchment 3. Platinum levels by ashed-ICP–MS are also low; variations in concentration are likely related to analytical variation.

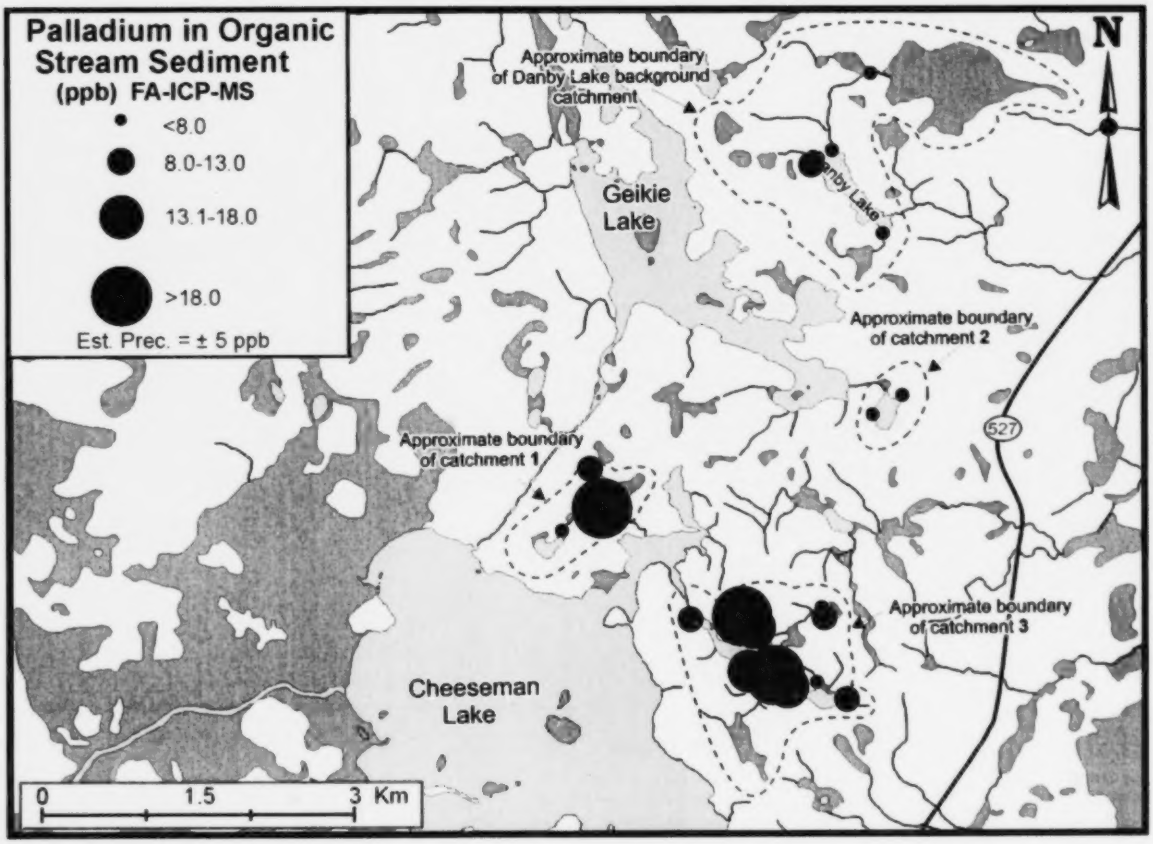

Palladium in Organic Stream Sediment
(ppb) FA-ICP-MS
● <8.0
● 8.0-13.0
● 13.1-18.0
● >18.0
Est. Prec. = ± 5 ppb
N
Approximate boundary of Danby Lake background catchment
Danby Lake
Geikie Lake
Approximate boundary of catchment 2
527
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cheeseman Lake
0
1.5
3 Km

Figure 35. Palladium in organic stream sediment, Cheeseman Lake study area.

Comparison of the Au results from the 3 methods of analysis show fairly good correlation. The Au by INAA data (Figure 36) shows the best contrast between the anomalous catchments (median of 9.1 ppb from 12 samples) and the background catchment (median of 2.3 from 6 samples). Anomalous catchment 1 had the highest single Au value of 19.5 ppb. Gold by ashed-ICP results were highest from anomalous catchment 1. The highest Au by FA value was 13 ppb from catchment 3. Gold results by Enzyme Leach^{SM} were mostly below detection limit. Considering the estimate of precision, the only value of possible significance came from anomalous catchment 3.

Summary

The Cheeseman Lake study area is a bedrock-controlled plateau underlain primarily by sills of diabase. The surface of the plateau contains numerous depressions of various sizes commonly filled with lakes. The lakes are rimmed by a series of bedrock-controlled steps or escarpments some exceeding 30 m in height. The surface of the plateau is also cut by curvilinear to linear valleys likely controlled by fracture systems developed in the sills. Areas of highly weathered sill rocks (to depths exceeding 3 m) tend to occur along valley edges and rounded corestones floor the valleys. These relations suggest that deeper weathering has occurred along fractures in the sills and that subsequently removal of the less cohesive weathered rock (residual soil) has produced the valleys.

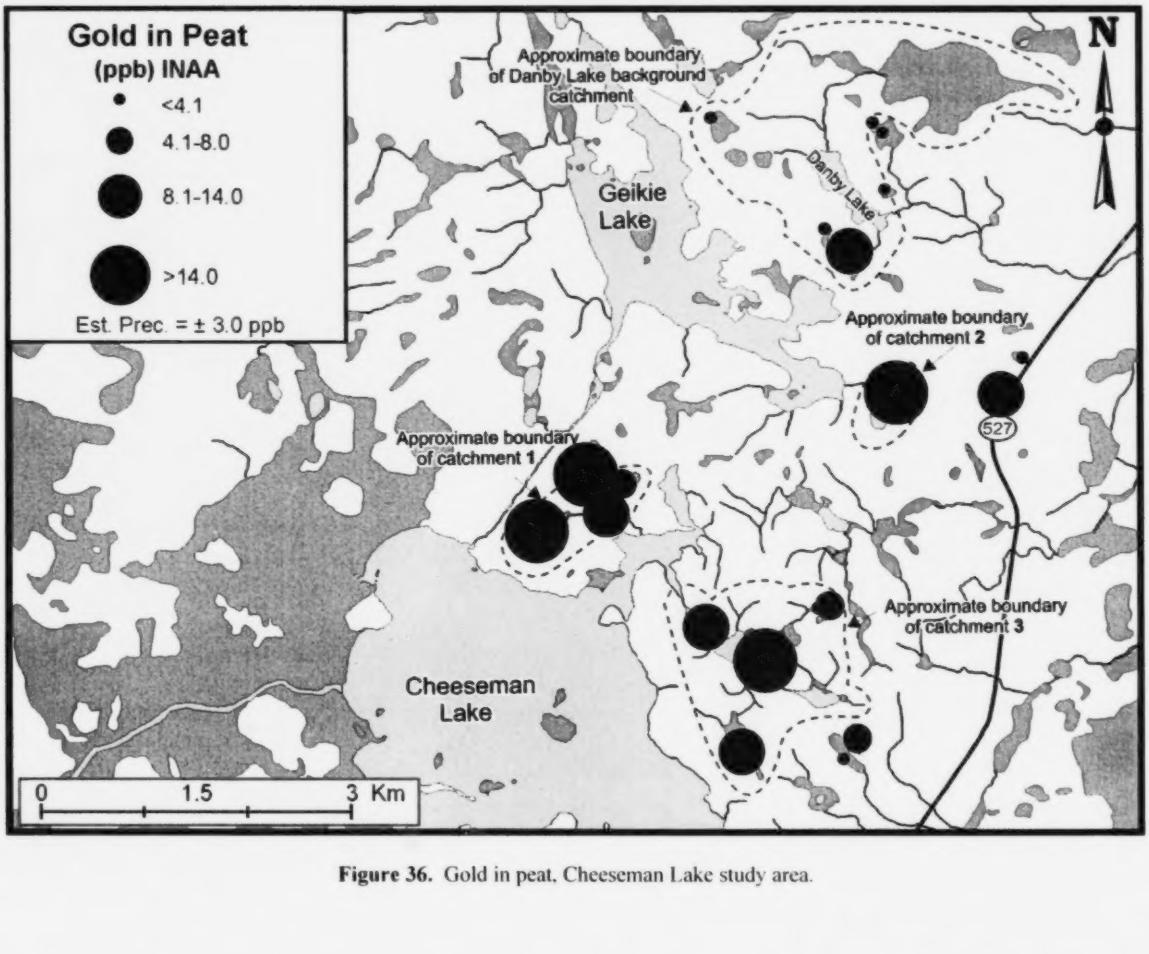

Gold in Peat
(ppb) INAA
● <4.1
● 4.1-8.0
● 8.1-14.0
● >14.0
Est. Prec. = ± 3.0 ppb
Approximate boundary of Danby Lake background catchment
N
Geikie Lake
Danby Lake
Approximate boundary of catchment 2
527
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cheeseman Lake
0
1.5
3 Km

Figure 36. Gold in peat, Cheeseman Lake study area.

The cover of till is thin and discontinuous. The lengths of water flow-paths (surface and groundwater) in contact with bedrock and particularly residual soil in this setting is much greater than that in till. As a result, the contribution of the till to the anomalous trace element concentrations lake sediment is probably minimal. Waters flowing in contact with the bedrock surface and through fractures and joints filled with loose granular residual soil most likely explain the lake sediment anomalies. Trace element values measured in residual soil samples could adequately explain the values obtained in the lake sediment geochemical survey (Dyer and Russell 2002). At Danby Lake, lake sediment geochemical survey results are lower (Dyer and Russell 2002) likely due to the thicker, more continuous till cover and lower initial element concentrations in the bedrock surrounding the lake (*see* Figure 32).

C-horizon till highlighted areas where several of the concentrations of trace elements of interest were elevated. B-horizon anomalies tend to occur where there was probably downslope movement of trace elements in groundwater from bedrock-controlled ridges. The same mechanism combined with organic fixing may explain the anomalies in Cu and Pd found in humus.

The results of the sampling project at the Cheeseman Lake study area demonstrate that significantly higher levels of the metals of interest are present and moving within the anomalous drainage catchments compared to the background catchment. This is, in part, due to the rugged bedrock-dominated terrain and the prevalence of coarse-grained, moderately to strongly weathered diabase (and associated residual soils) of the anomalous catchments. The highest levels of Cu, Pd and Au within the sampled bedrock are located within catchment 3. Within the "higher background" anomalous catchments, anomalous results for Au, Co, Cu and Pd vector to the east-central part of catchment 3 and anomalous results for Co, Cu, Ni and Pt vector to the west side of catchment 1 (Figure 37).

It is clear that the source of the Cu, Pd and Au determined in lake sediment is from the surrounding bedrock. The coarse-grained diabase, which has higher levels of Cu and Pd than the medium-grained (and relatively "fresh") diabase, is the dominant rock type observed within the anomalous drainage catchments. It is unclear if the intensity of the geochemical anomalies are due to a localized point source increase in mineralization; the effect of landscape (e.g., slope and/or relative lack of organics which might otherwise act to "decouple" the geochemical bedrock signal from the lake basins); or local variations in weathering intensity of the diabase. Native Cu, as well as chalcopyrite, have been observed in texturally and geochemically similar hematite-altered Nipigon diabase sills intersected by drilling in the Thread Lake–Pebble Lake area (Wagner 2003). In addition, Au levels up to 1 g/t in Nipigon sills have been documented (T.R. Hart, OGS, personal communication, 2005). Therefore, there is potential for the existence of localized point source mineralization that could account for the observed anomalous geochemistry.

CIRCLE LAKE STUDY AREA

Introduction

The Circle Lake case study area is a bedrock-controlled plateau underlain by diabase sills (Map 4, back pocket). It rises to over 120 m above the surrounding lowland areas. The southwestern end of the plateau consists of highly weathered sill rocks (to depths exceeding 3 m). Lakes occur in steep-walled fault-controlled valleys or within shallow or deep basins carved into the plateau surface. Glacial and postglacial sediments are thicker in the low-lying areas and along the western edge of the plateau. Large blocks of rock (talus), predominantly gabbro and/or diabase, mantle the lower slopes of the deep, narrow, steep-walled valleys in the Circle Lake study area.

Evidence of only one direction of ice flow (240 to 260°) was observed on outcrops within the area studied. Two large crag-and-tail features in the northern part of the case study area are oriented 243° and 249°. Till in the area is commonly a very thin discontinuous layer over the bedrock surface. It is a stony slightly silty-sand to sand till. Analysis of 12 samples of till matrix (C-horizon) averaged approximately 69% sand, 29% silt and 2% clay-size particles. The till also occurs within a series of northwest-trending ridges that range between 2 to 10 m in height. These ridges occur throughout the area with spacing between them ranging, in general, from 100 to 300 m. Similar in appearance to "washboard" or "DeGeer" moraines, the ridges are quite varied in composition including ridges composed of diabase (bedrock), boulders, till, flowtills, and stratified sand and gravel. In some areas, cross ridges oriented parallel to ice flow (240 to 260°) occur, producing a rectilinear pattern on air photographs reminiscent of crevasse fillings. Field observations suggest that the till and flowtill within the ridges is composed of subglacial debris and that most ridges formed along grounding lines of a floating ice margin. Several samples of till were collected from within and between the ridges for comparison purposes to see if ridge samples could be useful in mineral exploration studies.

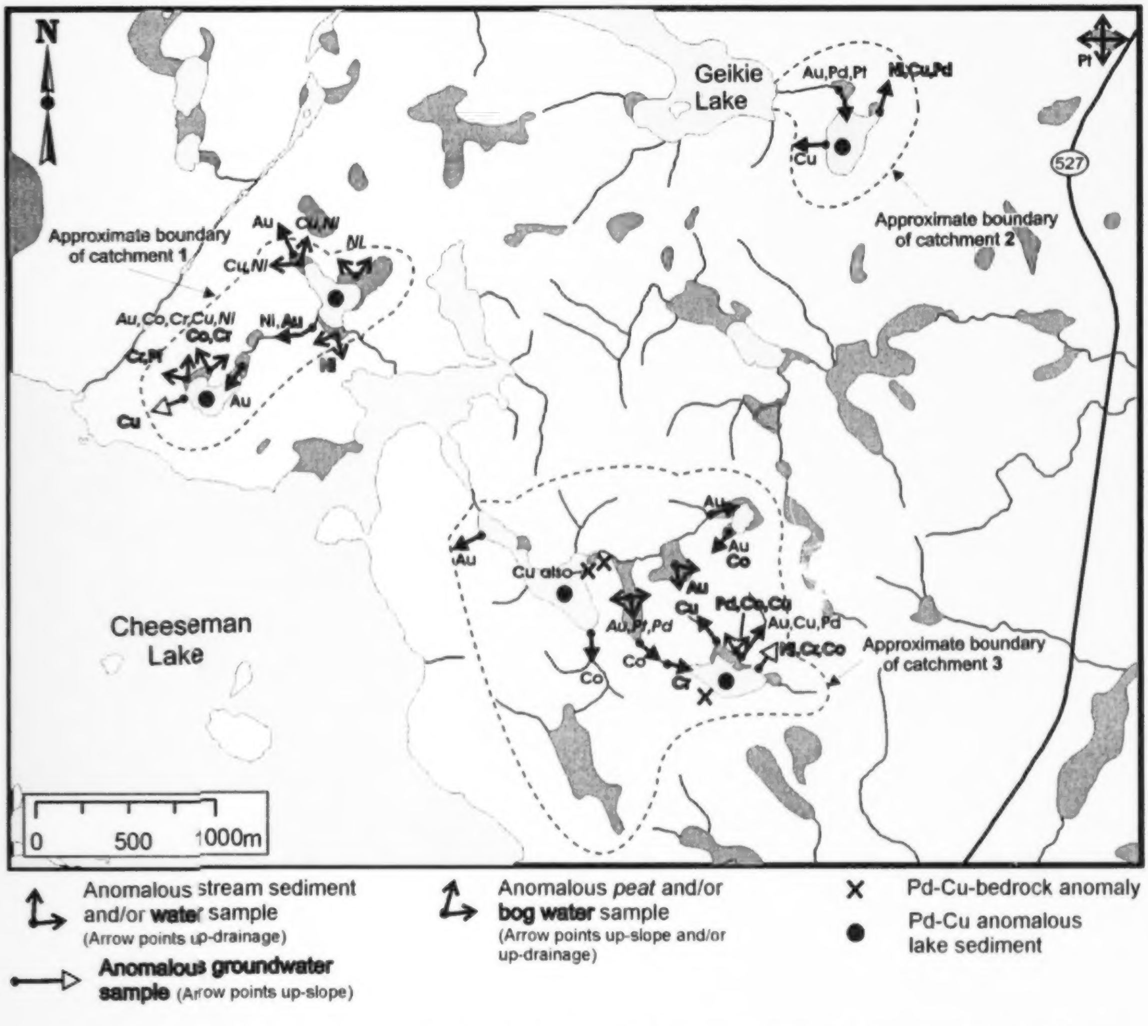

N
Geikie Lake
Au,Pd,Pt
Ni,Cu,Pd
Cu
Pt
527
Approximate boundary of catchment 2
Approximate boundary of catchment 1
Au
Cu,Ni
Cu,Ni
Ni
Au,Co,Cr,Cu,Ni
Ni,Au
Co,Cr
Cr,Pt
Ni
Au
Cu
Cheeseman Lake
Au
Au
Au
Co
Cu also
Au
Cu
Pd,Co,Cu
Au,Pt,Pd
Au,Cu,Pd
Ni,Cr,Co
Approximate boundary of catchment 3
Co
Co
Cr
0
500
1000m
Anomalous stream sediment and/or water sample (Arrow points up-drainage)
Anomalous peat and/or bog water sample (Arrow points up-slope and/or up-drainage)
Pd-Cu-bedrock anomaly
Pd-Cu anomalous lake sediment
Anomalous groundwater sample (Arrow points up-slope)

Figure 37. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, peat and stream sediments, Cheeseman Lake study area.

Stratified sand and gravel can also be found in large and small sinuous ridges (eskers) and ice-marginal fans and deltas within the Circle Lake study area. Sand of glaciolacustrine origin occurs beneath some of the low-level plains in the area, however, several of these plains are underlain by till. Finer textured glaciolacustrine sediments of silt and clay occur beneath the large lowland area to the west of the study area.

Humus was thick enough (up to 10 cm) for sampling at most sites. Common soil horizons observed include Bf, Bm, BC and C. The Ae horizon was rare and where present, very thin. Tops of the C-horizon generally occur 50 to 60 cm below the ground surface. The B-horizon developed in till is finer compared to that of the C-horizon. Analysis of 8 samples of till matrix (C-horizon) averaged approximately 66% sand, 32% silt and 2% clay-size particles. This is due to the breakdown and relocation of particles of the original parent material by soil forming processes.

Till commonly forms only a veneer over the bedrock surface on plateau tops and tends to be thicker along plateau slopes. On the plateau tops, B-horizon soils are commonly developed in bedrock (residual soil), not till, and the Type 5, "geogenic", soil geochemical soil profile type of Klassen (2003) occurs. At several sites, the till cover over bedrock was too thin to collect B- and/or C-horizon till samples. At these sites, the weathered bedrock or residual soil was noted and sampled. B- and C-horizon samples of both till and residual soil were collected during this study, however, consideration of this was taken during the interpretation of geochemical results for B- and C-horizon samples.

The development and preservation of residual soils is not uncommon in areas underlain by mafic to ultramafic rocks and, in particular, the Nipigon diabase sills. Areas of deep (>3 m) residual soils occur in the down ice-flow protected side of rock knobs and ridges indicating that the weathering processes may have operated prior to the last glacial event. However, large rotted boulders in till and glacial gravel and sand deposits and weathered bedrock beneath till in unprotected areas, such as plateau surfaces, indicate that the disintegration and weathering of the bedrock are also postglacial and ongoing processes.

The Nipigon diabase sills are composed of medium- to coarse-crystalline feldspar and pyroxene that should properly be classified as gabbro (Hart and Whaley 2004). Gabbro is approximately 10 times greater than diabase with respect to water absorption (Kazi and Al-Mansour 1980) and "rocks with high absorption values will be more susceptible to both physical and chemical weathering" (Gerard 1988, p.90). The coarse-textured nature of the sills, the extensive joints and fractures combined with the mineralogy and water absorption characteristics support both physical and chemical weathering processes. Deep weathering occurs downward from the surface and along fractures and joints producing a granular residual soil with the development of corestones near the base of the weathering front. Analysis of 2 samples of residual soil (C-horizon) averaged approximately 88% sand, 11% silt and 1% clay-size particles. The granular nature of the residual soil developed in the Nipigon sills promotes water movement through the soil (relatively high permeability), greater mineral–water interactions and deeper soil development (enhanced soil-forming processes) within the bedrock. Analysis of 2 samples of residual soil (B-horizon) averaged approximately 61% sand, 36% silt and 3% clay-size particles. The increase, 27%, in finer grained particles in the B-horizon is due to the breakdown and relocation of particles of the original parent material by soil-forming processes.

The results of deeper soil development in these rocks are displayed by the occurrence of loose granular gabbroic sand (residual soil) along fractures and joints adjacent to competent gabbro at depth. Surface and groundwater has transported minerals and rock fragments downstream to be deposited as stream and/or lake sediment. Elements, such as Pd and Cu and, to a lesser extent, Pt and Ni, likely move in solution as well and potentially affect levels of these elements in both stream and lake water.

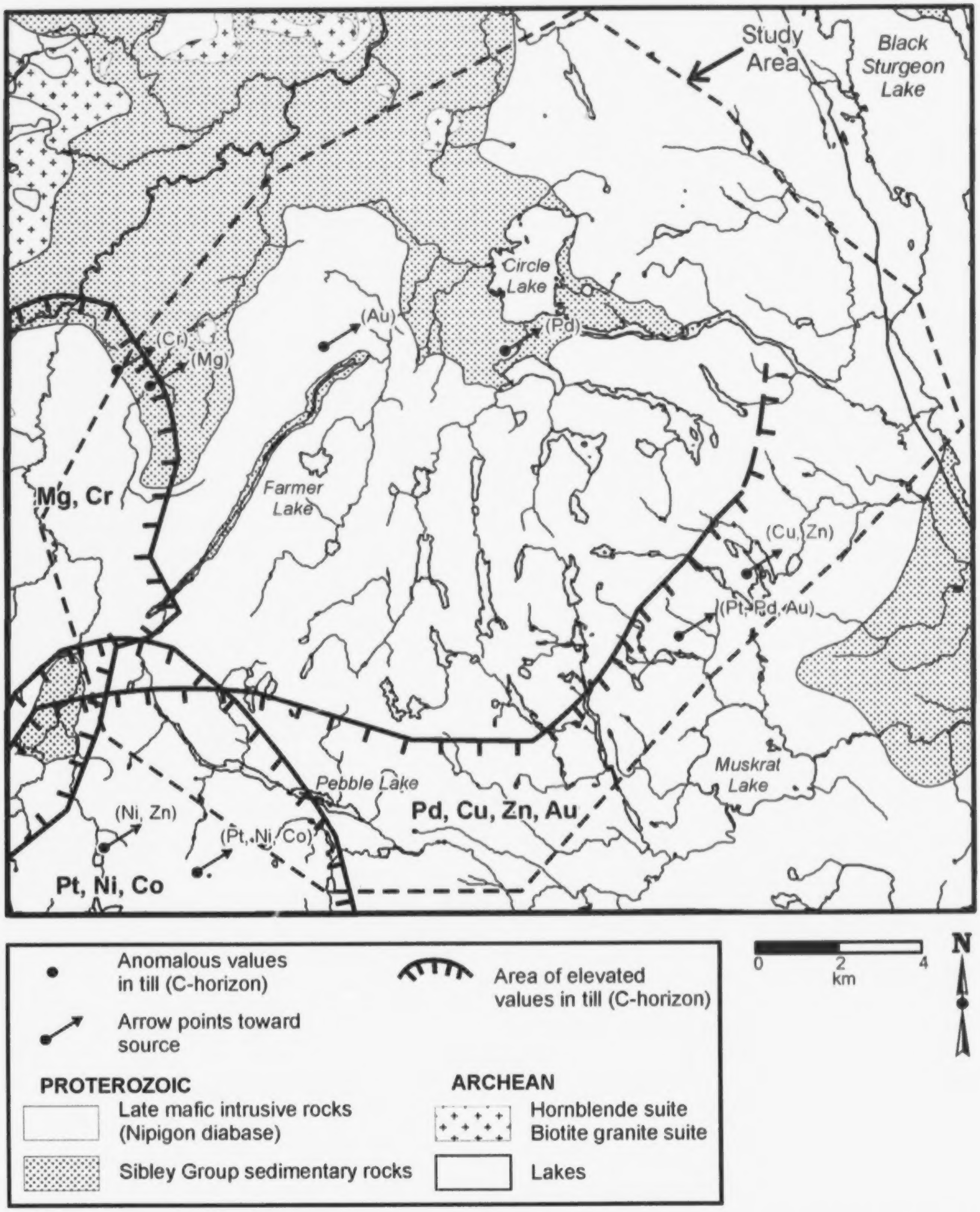

Study Area
Black Sturgeon Lake
Circle Lake
(Au)
(Pd)
(Cr)
(Mg)
Mg, Cr
Farmer Lake
(Cu, Zn)
(Pt, Pd, Au)
Muskrat Lake
Pebble Lake
Pd, Cu, Zn, Au
(Ni, Zn)
(Pt, Ni, Co)
Pt, Ni, Co
0
2
4
km
N
Anomalous values in till (C-horizon)
Arrow points toward source
Area of elevated values in till (C-horizon)
PROTEROZOIC
Late mafic intrusive rocks (Nipigon diabase)
Sibley Group sedimentary rocks
ARCHEAN
Hornblende suite Biotite granite suite
Lakes

Figure 38. Distribution of anomalous ($\bar{x}+2\sigma$) samples and areas of regionally elevated PGE and associated elements from C-horizon till samples with vectors toward source areas, Circle Lake study area. Elements in brackets are anomalous values in individual till samples and element assemblages not in brackets are related to areas of elevated concentrations.

Till: Glacial Dispersal

Till can be used in the Circle Lake study area for mineral exploration, however, it can be difficult to obtain C-horizon till samples. The main reason for this is that, in some parts of the study area, till is very thin and discontinuous. In these areas, soil-forming processes have affected the entire thickness of the till making the collection of C-horizon samples impossible. Geochemical results from the C-horizon till samples collected are of interest, however, despite the factors affecting their spatial distribution.

HEAVY MINERAL RESULTS

Six samples from the Circle Lake study area were processed by GeoLabs and underwent analysis for heavy minerals to obtain the overall heavy mineral assemblage in till from this area. The average heavy mineral composition consists of about 72% clinopyroxene, 9% calcic amphibole, 7% orthopyroxene, 3% fayalite, 3% ilmenite and minor amounts (<2%) of sub-calcic amphibole, forsterite and epidote. These minor constituents can be of interest in mineral exploration (Averill 2001).

In addition, 7 heavy mineral samples collected from stream sediment were processed and analyzed by Overburden Drilling Management Limited (ODM) of Nepean, Ontario. The reports provided by ODM concentrate on the important minor constituents or indicators of mineralization of the heavy mineral assemblages and results are contained in MRD 154.

Overburden Drilling Management Limited recognized several mineral assemblages within the Circle Lake set of samples. Pigeonite dominated the assemblages that also included fayalite, titanite, diopside and/or epidote.

No mineral grains containing platinum or palladium were recovered from the 7 samples collected in the Circle Lake study area. A reshaped gold grain was recovered from a stream sediment sample (03-PJB- 221) collected from a small creek draining into the west shore of Circle Lake. There were no kimberlite indicator minerals reported from the Circle Lake area samples. Very few other indicator minerals were recovered. Sample (03-PJB- 208), collected from a small creek entering the small lake immediately southwest of Thread Lake, contained 30% fayalite, but no other indicator minerals. Sample 03-PJB- 215 contained 7% fayalite and the remainder of the samples 3% or less. Three samples, 03-PJB-219, 03-PJB- 224 and 03-PJB- 251, contained only 1 grain of chalcopyrite. Sample 03-PJB- 219 also contained 1 grain of Mn-epidote and 3% fayalite; 03-PJB- 224, 1 grain of Mn-epidote and 1% fayalite; and sample 03-PJB- 251, a trace of sillimanite and 2% fayalite. Sample 03-PJB- 221 contained 2% fayalite, 1% sillimanite and a grain each of Mn-epidote and low Cr-diopside.

C-HORIZON TILL SAMPLE GEOCHEMICAL RESULTS

C-horizon till is material that was deposited directly from the glacier with little to no alteration as a result of soil-forming processes or weathering. Samples of till indicate the physical dispersal of rock fragments and minerals from bedrock sources by glaciers in the down glacier ice-flow direction. Sampling density in the Circle Lake study area was not sufficient to delineate discrete dispersal trains associated with mineralization, however, the distribution and values obtained from the geochemical analysis of the samples collected are of interest for several elements. In C-horizon till samples, 3 spatial geochemical associations can be recognized: 1) Pd, Au, Cu and Zn; 2) Pt, Co and Ni; and 3) Mg and Cr (Figure 38).

The results discussed below are based on fire assay and ICP for PGEs and ICP for the other trace elements. A summary of the results is presented in Table 5. Results for all the geochemical analyses performed are contained in MRD 154.

Platinum Group Elements

In the Circle Lake study area, 2 C-horizon till samples (Cir-Soil- 2023 and Cir-Soil- 2038) contain anomalous Pt. One is a regional till sample collected about 2.5 km southwest of Pebble lake, the other occurs within anomalous catchment basin area 1 (*see* Figure 38; *see also* Figure 41 for location of anomalous catchment areas).

Two C-horizon till samples were anomalous with respect to Pd (Cir-Soil-2015, Cir-Soil-2038). The same sample that was anomalous with respect to Pt within the anomalous catchment basin area 1 (Cir-Soil- 2038) and a sample of till collected approximately 350 m northeast from Rabbitbelly Lake. Palladium concentrations were 18.2 and 16.2 ppb, respectively. An anomalous Au value (7.1 ppb) was also obtained from sample Cir-Soil-2038 within anomalous catchment study area 1 and in sample Cir-Soil-2018 (6.2 ppb Au) collected about 2.5 km north of Farmer Lake (*see* Figure 38).

Associated Elements

Broad, regional, dispersal trains for several trace elements that are commonly associated with Pt and Pd occur in the Circle Lake study area. The general trends of the distribution of Pd, Au, Cu and Zn in C-horizon till samples are similar. Elevated concentrations for these trace elements occur within anomalous catchment study area 1 or 3 and the area south of Pebble Lake. Anomalous values in the Cu and Zn content were obtained in a C-horizon till sample collected within anomalous catchment area 3. Sample Cir-Soil-2021 also contained anomalous levels of Zn.

Platinum, Ni and Co spatial distributions are alike and the distribution patterns of Mg and Cr in C-horizon till samples are also similar. Anomalous values of Mg and Cr in C-horizon till samples occur within the lowland area along Lime and Boulder creeks. Unlike the Lac des Iles case study area, there is no positive relationship between the concentrations of PGEs to those of Mg and Cr. Samples with anomalous concentrations of Ni (>93 ppm) and Co (>30 ppm) were all collected southwest of Pebble Lake.

Distributions of these elements in C-horizon till for the most part reflect chemical differences in the Nipigon sills that crop out within the Circle Lake study area (MacDonald, Tremblay and Easton 2005; MacDonald and Tremblay 2005). Differences occur, however, along the western and southern margins of the area, where the incorporation of other rock types may have altered this relationship. There is, for example, an increase in Sibley Group clasts in pebble counts collected along the western margin of the case study area.

Till: Soil Profile Geochemistry

Following deglaciation, the materials making up the land surface were exposed to weathering and soil-forming processes. The parent material (C-horizon) of the soil began to alter physically and chemically in response to these processes and other soil horizons formed. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter) was also sampled during this project.

In all of the case study areas that have soils developed entirely in till, there is generally a decline in concentrations of Pt, Pd, Ni, Cu, and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This is generally the case at the Circle Lake case study area. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7). Many sites, particularly those on plateau surfaces in the Circle Lake study area, however, have Type 5, "geogenic", profile, that is, different materials, stratigraphy, within the soil profile or a change in parent material through the soil profile (Klassen 2003; *see* Figure 7). At these sites, there is also a chemical disjunct between the thin layer of till at the surface and the weathered bedrock or residual soil making up the mineral soil layer at depth. In this case study area, where it was important to determine the contribution of each media to lake sediment geochemical anomalies within the catchment basin lakes (Dyer and Russell 2002), humus, B- and C-horizon samples were collected regardless of the origin of the parent material. As a result, only a few B- and C-horizon till samples and samples of humus formed over complete soils developed in till could be collected and analyzed, particularly in the anomalous catchment basin areas.

Sites that did contain the B- and C- horizon mineral soil horizons developed in till, commonly fall into the Type 1 profile, "leaching", that is, a net downward increase in element concentration, for Pt, Pd, Ni, Cu, Cr and Co. Variations in Pt and Pd concentration between the various soil horizons at many sites were less than the error of laboratory measurements, however, the general decrease in concentration up soil profiles trend remains.

Gold and Zn commonly illustrates the Type 2, "accumulation (surface)", geochemical profile type in soil profiles developed in till from the case study area (Klassen 2003; *see* Figure 7). For these elements, biological processes are the preferred mechanism of enrichment in humus samples.

The soil profile geochemistry of Pt is similar to that of Pd. In general, Pt concentrations are higher than Pd at most sites investigated. The mobility or degree of decrease in concentration up the soil profile is less with Pd than Pt, which is reverse to most other case study areas. Copper is very mobile in soils in the Circle Lake study area. There is a general trend for the concentration of Ni to decrease up through the soil profiles developed in till. There is not as much removal of Ni as occurs with Cu in the B-horizon, that is, the geochemical gradient or mobility is not as great for Ni as Cu in soil developed under Circle Lake area soil and climatic conditions. At some sites, Zn, Cr and Ni concentrations in B-horizon samples are greater than in C-horizon samples. These results possibly reflect down-ice dispersal of Ni where the Ni content in the C-horizon samples at these sites may have been diluted by local incorporation. The overall concentration of most of the elements discussed herein (except Ni and Cr) is several times higher in bedrock or residual soil samples than in the till samples collected in the Circle Lake study area. Results of the analysis of B-horizon and humus samples are included in MRD 154.

Platinum was anomalous in 3 B-horizon samples, Cir-Soil-1021 and Cir-Soil-1023 south of Pebble Lake, and 1 sample, Cir-Soil-1038, in "anomalous catchment basin 1" (Figure 38).

Palladium, Au and Cu are anomalous in 2 B-horizon till samples (Cir-Soil-1031 and Cir-Soil-1038) in "anomalous catchment study area 1 and 3", respectively. Nickel concentration in one sample (Cir-Soil-1021), located south of Pebble Lake, was anomalous. Anomalous Pt, Zn and Co concentrations occur in this B-horizon sample as well as elevated levels of Ni in the underlying C-horizon sample at this site. Another anomalous Co sample (Cir-Soil-1038) is from anomalous catchment basin 1 and a Zn anomaly in the B-horizon (Cir-Soil-1030) from "anomalous catchment basin 3".

Residual Soil: Soil Profile Geochemistry

Soils are also developed in bedrock or areas where there is a thin cover of till overlying bedrock in the Circle Lake study area. In soils developed entirely in bedrock, there is generally a decline in concentrations of Pt, Pd, Ni, Cu, and Cr up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (*see* Figure 7), of the 5 basic geochemical profile types proposed by Klassen (2003). In the composite thin till over bedrock settings, a Type 5, "geogenic", geochemical soil profile occurs (Klassen 2003; *see* Figure 7). However, as a result of the large difference between the initial trace element concentrations in the bedrock and that in the till, there is a decline in concentration of Pt, Pd, Ni, Cu, and Cr up through the soil profile (Type 1: Klassen 2003). There are also major decreases in Pt, Pd and Au concentrations from B-horizon samples developed in residual soil and in corresponding humus samples.

RESULTS OF HUMUS SAMPLING

Concentrations of most elements evaluated are generally lower in humus samples collected from the Circle Lake study area. The concentrations of Au and Zn being the exceptions where the soil is developed in till. Copper and Pd reach anomalous values in humus (sample Cir-Soil-0040) within anomalous catchment area 1. The concentration of Pt in humus sample, Cir-Soil-0029, is anomalous. Two humus samples along the western shore of Thread Lake are anomalous in Ni and one sample to the east of Thread Lake is anomalous in Cr content. All of the anomalous humus samples have developed on weathered bedrock or residual soil or weathered bedrock with a very thin cover of till. Biological processes may explain these elevated element concentrations in humus at these sites.

Lake Sediments

The Circle Lake study area features a broad Cu-Ni-PGE multi-site lake sediment anomaly, which was identified by a regional OGS lake sediment survey (Dyer and Russell 2002). Anomalous values for Pd and Pt in this area range up to 38.5 ppb and 14.2 ppb, respectively. Highly anomalous Cu (up to 637 ppm) and Ni (up to 100 ppm) characterize many of the anomalous PGE lake sites. A distinct zonation of the lake sediment anomalies is apparent. Palladium, Au and Cu anomalous lakes occur dominantly on the east side of the study area and Ni-Pt anomalies occur on the west side. Re-sampling for verification was completed under this project for 11 lake sites. In-fill sampling was carried out on 4 lakes located on the eastern side of the study area for more complete coverage. The results for Cu and Ni from this additional sampling confirm the original levels and pattern of east-west zonation. Gold and Pd results by FA–ICP–MS were marred by poor reproducibility of the OGS internal standard. Despite this, Pt reproduced the pattern of anomalous levels along the Pebble–Thread lakes drainage systems, in contrast to low levels on the east side of the study area. Three drainage catchments with anomalous lake sediment geochemistry were targeted for detailed multimedia sampling under this project. In addition, a small lake approximately 2.5 km southeast of Thread Lake, within anomalous catchment area 2, was selected as a background lake. This lake had no significant lake sediment geochemical anomalies.

Lithogeochemistry

A total of 60 bedrock samples were collected in this case study area. Three samples of Sibley Group rocks (sites RAC-RK-5 and RAC-RK-39) were collected from the Thread Lake drainage valley;

Table 8. Comparison of whole rock analysis data and selected trace elements on diabase samples collected from the Cheeseman Lake and Circle Lake study areas.

	Pd (ppb)	Pt (ppb)	Au (ppb)	Ni (ppm)	Cu (ppm)	Cr (ppm)	Co (ppm)	Al_2O_3 (%)	CaO (%)	Fe_2O_3 (%)	K_2O (%)	MgO (%)	MnO (%)	SiO_2 (%)	TiO_2 (%)	Mg#
Cheeseman Lake area: anomalous catchment diabase (coarse grained and weathered) (n=22)																
mean	33.3	3.6	6.9	52.4	270.6	21.7	61.7	12.1	9.1	19.8	0.6	4.7	0.3	48.8	2.5	0.3
median	**25.3**	**3.3**	**5.6**	**52.3**	**266.1**	**18.4**	**60.7**	**11.8**	**9.0**	**19.9**	**0.6**	**4.6**	**0.3**	**48.8**	**2.4**	**0.3**
stdev	17.9	1.3	3.5	21.1	70.2	15.4	11.0	1.2	0.6	2.2	0.1	0.9	0.02	1.4	0.6	0.1
min	18.1	1.7	3.0	11.6	124.8	6.9	48.3	10.1	7.4	16.3	0.47	2.5	0.21	45.9	1.6	0.19
max	83.4	6.6	15.2	93.4	424.8	58.8	88.2	14.6	10.2	24.3	1.1	6.2	0.3	51.7	3.8	0.4
Circle Lake area (east): anomalous catchment diabase (coarse grained and weathered) – Upper Sill? (n=12)																
mean	58.2	16.1	8.6	35.5	260.6	16.3	56.2	11.5	7.9	20.5	0.9	3.9	0.3	49.4	2.6	0.3
median	**36.3**	**13.5**	**7.9**	**27.4**	**266.6**	**8.5**	**56.1**	**11.2**	**7.9**	**20.6**	**0.9**	**3.8**	**0.3**	**49.2**	**2.7**	**0.3**
stdev	59.6	10.9	6.1	21.4	64.3	21.4	7.8	0.8	0.9	1.7	0.2	1.0	0.03	1.0	0.3	0.1
min	10.8	7.4	2.3	12.2	172.0	7.1	41.4	9.9	6.1	16.9	0.51	2.6	0.23	47.5	1.8	0.19
max	227.8	48.8	25.4	72.1	349.9	82.6	64.8	12.6	9.1	24.2	1.3	5.8	0.3	51.0	3.1	0.4
Circle Lake area (east): anomalous catchment diabase (medium grained) – Upper Sill? (n=25)																
mean	14.4	7.8	3.3	102.0	148.3	84.4	55.2	14.4	10.8	13.4	0.5	6.6	0.2	50.4	1.2	0.5
median	**13.1**	**6.6**	**2.8**	**100.7**	**135.9**	**93.1**	**53.8**	**14.5**	**10.9**	**13.4**	**0.4**	**6.6**	**0.2**	**50.3**	**1.1**	**0.5**
stdev	5.7	3.4	1.4	33.3	48.4	39.7	8.5	0.8	0.9	1.3	0.1	0.8	0.02	0.5	0.3	0.04
min	6.9	3.6	1.5	49.0	75.1	19.9	44.2	12.9	9.0	11.5	0.31	4.9	0.17	49.1	0.7	0.37
max	29.9	17.2	7.3	170.2	249.8	153.5	78.5	15.8	12.2	16.7	0.7	8.6	0.2	51.4	2.0	0.6
Circle Lake area (west): anomalous catchment diabase (medium grained) – Upper Sill (n=16)																
mean	14.9	12.2	3.2	187.6	129.2	102.9	61.2	15.3	9.6	13.4	0.6	7.8	0.2	48.8	1.1	0.5
median	**14.8**	**11.1**	**3.4**	**186.4**	**139.2**	**90.1**	**59.5**	**15.4**	**9.8**	**13.8**	**0.5**	**7.7**	**0.2**	**49.0**	**1.2**	**0.5**
stdev	3.8	3.3	1.4	23.8	38.6	31.0	7.3	0.5	1.1	1.2	0.3	0.9	0.02	0.7	0.1	0.0
min	8.8	5.4	<1	147.3	20.1	67.1	51.4	13.9	6.6	9.1	0.33	6.3	0.14	47.0	0.9	0.49
max	25.1	17.7	5.0	256.2	181.5	178.7	74.9	15.9	10.7	14.4	1.5	10.0	0.2	50.1	1.3	0.7

otherwise, all samples collected were identified in the field as diabase. Two texturally distinct "types" of diabase were encountered: 1) a medium-grained relatively unweathered, "fresh" diabase, and 2) a coarse-grained to very coarse-grained, moderate to strongly "weathered" diabase. A comparison of selected major, minor and trace elements between diabase samples from the Cheeseman Lake area and the Circle Lake area is contained in Table 8, including mean and median levels of the metals of economic interest. This table shows the Circle Lake study area diabase can be separated into 3 groups: 1) medium-grained "fresh" diabase collected along the Thread Lake drainage, "Circle west medium-grained diabase"; 2) medium-grained "fresh" diabase from the eastern side of the study area, "Circle east medium-grained diabase"; and 3) coarse-grained "weathered" diabase from the eastern side of the Circle study area, "Circle east coarse-grained diabase". For comparison, data for coarse-grained "weathered" diabase from the Cheeseman Lake study area ("Cheeseman coarse-grained diabase") from anomalous catchments are included. Of note are the strong similarities between the coarse-grained diabase from the Cheeseman Lake and Circle Lake study areas, the strong similarities between the medium-grained "fresh" diabase from the east and west sides of the Circle Lake study area, and the strong difference between the geochemistry of the medium-grained and coarse-grained varieties of diabase. The whole rock analysis results and REE data (e.g., Gd/Yb versus La/Sm, *see* Figure 30) show that all of these rocks plot within the well-established field for Nipigon sills. However, the majority of the diabase samples from the Circle Lake study area, shown on Figure 30, plot slightly higher than the Cheeseman Lake area rocks and overlap the Cheeseman field. On a Zr/Y versus Mg# plot (Figure 39), the Circle Lake study area medium-grained "fresh" diabase samples plot higher (Mg numbers between 0.45 and 0.60) than the coarse-grained Circle Lake and Cheeseman Lake study area rocks.

The overlap of Circle Lake and Cheeseman Lake area coarse-grained diabase, as shown in Figure 39, indicates the possibility of a time-stratigraphic equivalence. The wide scatter of Mg# for the east Circle Lake area diabase samples indicates significant geochemical variation is occurring in the eastern diabase sill over a relatively short vertical distance. This geochemical distinction or variation between texturally different diabase may be normal within a single sill unit; similar variations have been documented in the lithogeochemical results from diamond-drill holes near Muskrat Lake (T.R. Hart, OGS, personal communication, 2005). There is also the possibility that geochemically distinct sill units exist.

The majority of the samples of diabase collected on the west side of the Circle Lake study area were obtained along the sides of the Thread Lake drainage valley. Analytical results from 16 samples returned average levels of Ni (187 ppm), Cr (102 ppm) and MgO (7.8%) that are significantly higher than the averages obtained from the eastern diabase samples. Conversely, average levels of Cu, Au and Pd are higher in the eastern diabase samples. This east–west geochemical zonation is also reflected in the lake sediment results discussed previously. The highest Cu, Pd, Pt and Au levels occur in the coarse-grained diabase within anomalous catchments 1 and 3.

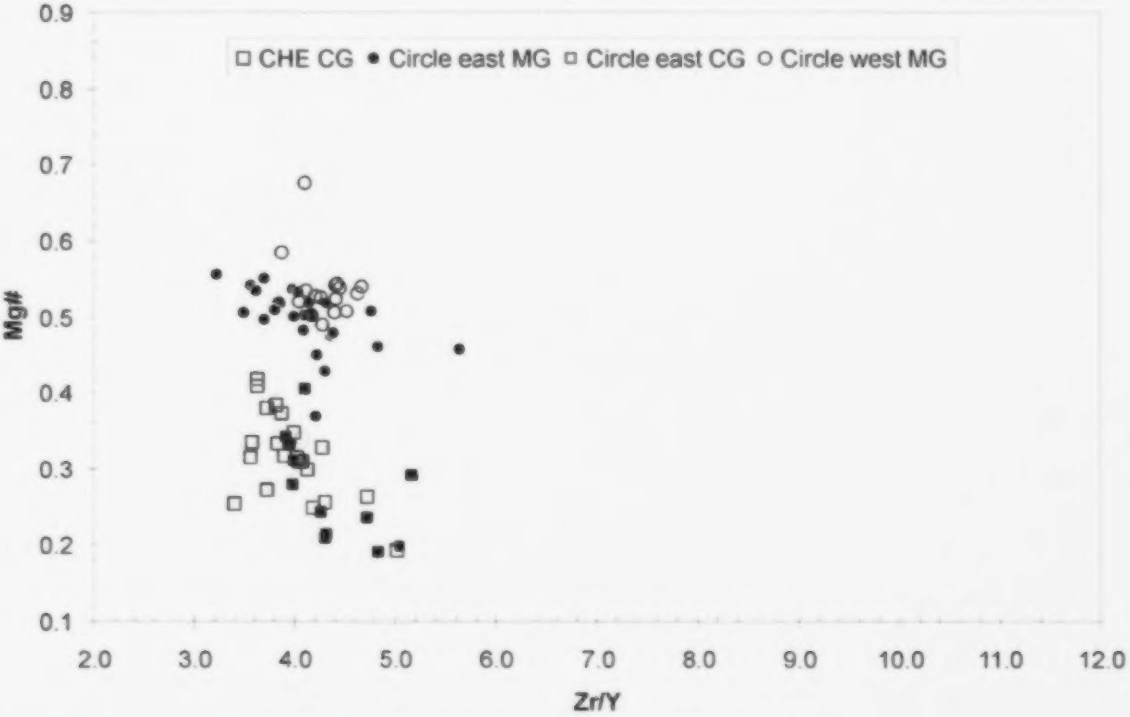


Figure 39. Zr/Y versus Mg# diagram for rock samples collected in the Cheeseman Lake (CHE) and Circle Lake (east and west) study areas subdivided by rock texture (grain size). Other abbreviations: CG, coarse grained; MG, medium grained.

Diamond drilling near Thread and Pebble lakes intersected 2 distinct diabase sills separated by an approximately 50 m thick unit of Sibley Group rocks (Wagner 2003). Lithogeochemical results from the drill core samples show that the upper sill has significantly higher levels of Ni and Pt than the lower sill. In the lower sill, Wagner (2003) notes that where the diabase becomes coarse grained, there is a marked increase in Pt, Pd, Au and Cu (but decreased Ni and Cr). This is analogous to the results of the surface bedrock sampling along the Thread Lake valley compared to the results from the eastern diabase samples. Figure 40 shows a west to east schematic cross-section from Thread Lake to anomalous catchment area 1, looking toward the northeast. Assuming the diabase and Sibley Group units are approximately flat lying, and the Rossport Formation is correlatable from east to west, this cross-section suggests a higher level of the upper sill is present underneath the Cu-Pd-Au anomalous catchments in the east.

Hydrogeochemistry

Lake water pH within the study area ranged from 6.7 to 7.4, with an average of approximately 7.0. Overall, stream water pH also averages approximately 7.0, although the eastern side of the study area has slightly more acidic waters (average pH=6.9) compared to the Thread Lake drainage system (average pH=7.4) on the west side. The presence of dolomitic Sibley Group rocks along the Thread Lake drainage may be the cause of this slightly higher pH level. Bog waters tend to be slightly acidic with an average of approximately pH 6.4, likely due to natural organic acids. In general, pH conditions are near neutral and therefore conducive for the transport of metals hydromorphically.

The conductivity of surface waters of the Thread Lake drainage system differs from the other catchments. The east side catchments (anomalous catchments 1 and 3) have water conductivities

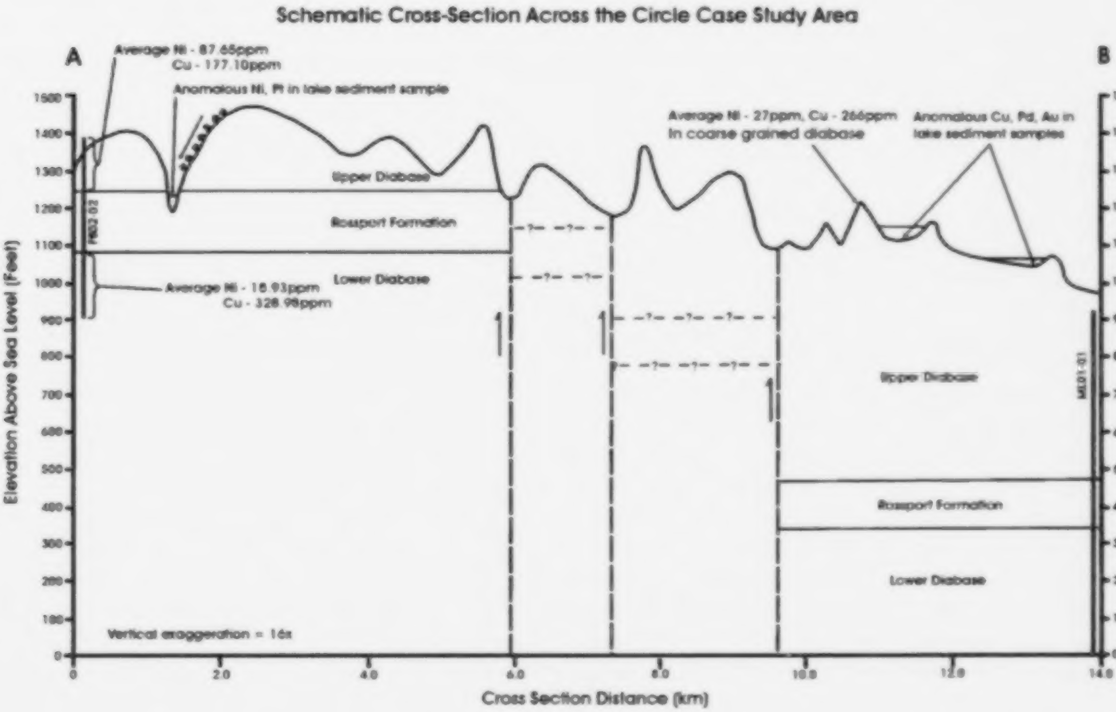


Figure 40. A west to east schematic cross-section (A–B) across the Circle Lake study area, looking toward the northeast. The location of the transect, from Thread Lake to anomalous catchment 1, is indicated on Figure 41. The 2 diamond-drill holes (PB02-02 and ML01-01) shown at the ends of the section are located approximately 1 km south of the section.

averaging ~60 µS/cm. The Thread drainage system averages ~100 µS/cm, indicating a higher level of total dissolved solids. This is likely due to the high valley walls and presence of talus slopes (mass wasting) that occur along the Thread Lake drainage. The geochemical results show higher levels of major elements (such as Ca and Mg) are being contributed to the waters of the Thread Lake drainage system; this may be due to the presence of Sibley Group rocks.

LAKE WATERS

A total of 28 lake waters were sampled in this case study area. In lake waters, Pd, Au and Cr are present at very low levels, often below detection limit. However, Ni and Pt are distinctly elevated along the Thread and Pebble lakes drainages, compared to the rest of the study area. Average Ni content of the lake waters sampled is the second highest of all the case study areas (after Lac des Iles). Copper is elevated in the water of the small lake upstream of Thread Lake in anomalous catchment 2 and at several lakes within anomalous catchment 1.

STREAM WATERS

A total of 75 stream water samples were obtained across the study area. For comparison, 22 stream waters were also collected as near as possible to the Seagull and Disraeli intrusions. The mean and median levels of Ni in stream water within the Circle Lake study area are lower than the Lac des Iles,

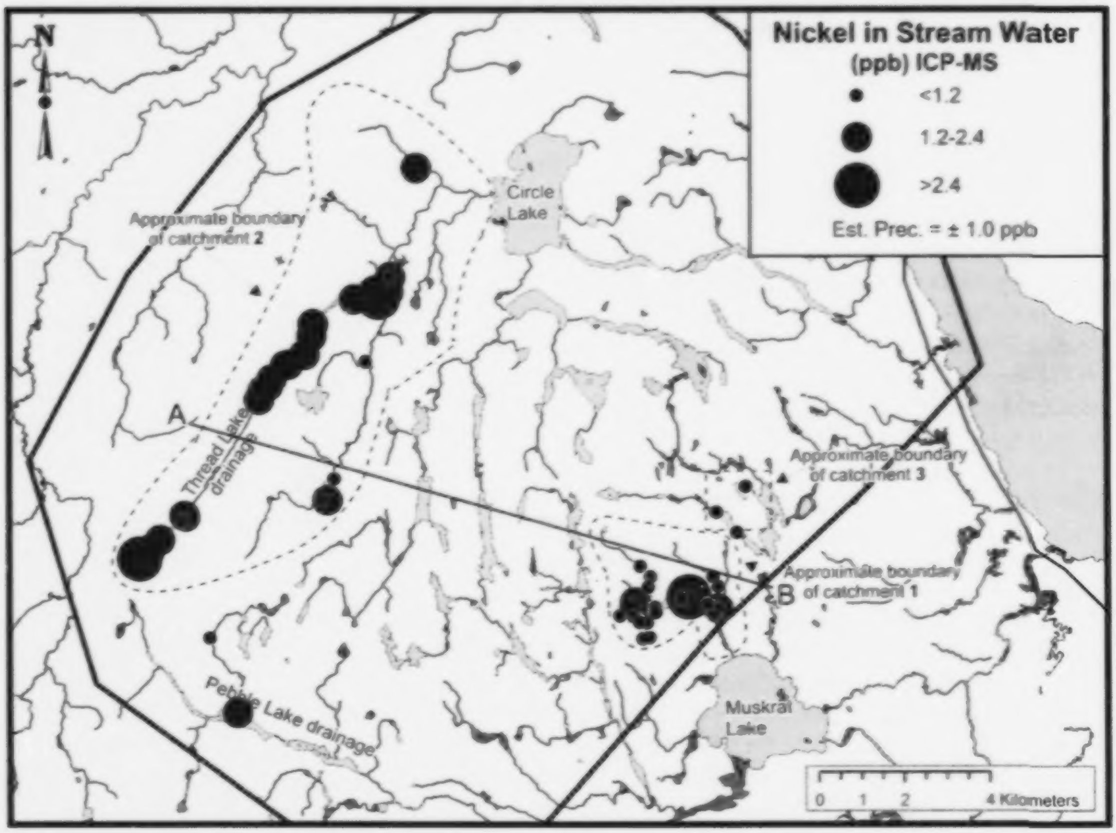


Figure 41. Nickel in stream water, Circle Lake study area. A–B indicates the transect for the cross-section shown in Figure 40.

Tib Lake and Seagull–Disraeli lakes study areas, but slightly higher than the Cheeseman Lake area. Conversely, mean and median levels of Cu are higher within the Circle Lake study area than the Lac des Iles, Tib Lake and Seagull–Disraeli lakes study areas, but 3 times lower than the Cheeseman Lake area.

The results for metals in stream waters show a similar pattern to that of the lake waters. Nickel (Figure 41) and Pt are consistently elevated along the Thread Lake drainage system compared to the other catchments. Conversely, Co and, to a lesser degree, Cu, Pd and Au are elevated on the east side of the study area within anomalous drainage catchment 1. In particular, Cu and Pd are anomalous at 2 sites located on the eastern side of catchment 1. Resampling of these 2 sites in 2004 replicated the Cu levels, but failed to return anomalous Pd. Higher levels of Co in stream water in the east within catchment 1 is not supported by higher levels of Co in bedrock. The difference may be due to the slightly acidic waters of catchment 1 and the higher mobility of Co under such conditions. All metals are present at low levels in the 2 inlet streams and the one outlet stream of the small background lake located within anomalous catchment 2.

SHALLOW GROUNDWATER

Groundwater was sampled from 11 springs, all except one of which was located along the Thread Lake drainage, emanating near the base of the valley. Groundwaters feeding the Thread Lake drainage are significantly higher in Cu (average 10 ppb) than surface waters, but levels of Pd and Pt are only marginally higher. The average level of Ni in these spring waters is no different than the stream water entering the Thread Lake drainage. The highest levels of Cu, Co, Ni, Pd, Pt and Au in the sampled groundwater occur at or near the southwest end of Thread Lake; there is a general trend to the northeast (downstream) of lower levels entering the drainage system from the sampled springs.

Bog water samples were collected at 7 sites from dug sumps. Four of the bog water sumps are located within the eastern anomalous catchments and 3 in background areas within catchment 2. This data set, although small, displays a clear difference in metal levels between anomalous catchment 3 and the background sites. The highest (anomalous) Cu value of 23.5 ppb occurs in catchment 3, in the bog fringe of a strongly Cu anomalous lake. Although at low levels, the highest values for Cr, Co, Au and Ni also came from this catchment. Palladium and Pt levels are low; the only significant Pd value came from catchment 1 and the 2 highest Pt results from the background sites in catchment 2. The 4 sampled bog waters in the anomalous catchments 1 and 3 have significantly lower pH (< 6.2) than the 3 background sites in catchment 2; this may account for at least some of the observed differences in metal levels.

Stream Sediments

A total of 48 inorganic stream sediments were collected from the Circle Lake study area. The most prominent pattern is the high concentration of the elements Ni (Figure 42), Pt and Co at the Thread Lake drainage compared to catchment 1 in the east. For example, Ni levels are typically <30 ppm within catchment 1, compared to >60 ppm in catchment 2 (Thread Lake). The most anomalous Ni value in catchment 2 was obtained at the southwest end of Thread Lake. Copper does not display such zonation as levels are roughly the same within these catchments. Anomalous levels of Cu (>300 ppm) occur at the southwest end of Thread Lake, the southwest corner of catchment 1 and approximately 2.5 km southeast of Thread Lake within the Pebble Lake drainage. Several elevated Cr values occur in catchment 1 and, in general, the levels are greater than within the Thread Lake drainage system (catchment 2). However, 2 anomalous Cr values were obtained from sites at the northeast end of the Thread Lake drainage. Gold by INAA returned similar levels at catchments 1 and 2. The highest value (18.4 ppb) came from within catchment 3, however, a field duplicate failed to replicate this result. The 2 highest results for Au and Pd by FA–ICP–MS came from catchment 1, otherwise, the levels obtained at each of the anomalous catchments were similar. All metal levels at the background lake within catchment 2 were low, except for a value of 4.9 ppb Au (FA).

Samples of sand were collected from the base of springs centred on deeply incised valleys along the Thread Lake drainage system. In essence, these are modern alluvium samples and the material likely originated from residual soil (weathered diabase) from the valleys. The results for both base and precious metals show the highest levels coming from 2 springs located at the southwest end of Thread Lake (sites RAC-SPR-1 and RAC-SPR-2). Results from the sand samples down drainage to the northeast are generally lower for all of the metals except for Pt and Cr. This vector to source corresponds with the results of the groundwater chemistry and stream sediments discussed above.

Organic stream sediments were collected at 17 sites, mostly within anomalous catchment 1. For comparison, 3 widely spaced creeks were sampled well away from this catchment to the west. The results for Au (INAA and FA), Cu, Co and Pd (FA) (Figure 43) show the best contrast with the background sites, with a consistently higher background and several strong anomalies. Platinum (FA and ashed-ICP), Pd (ashed-ICP) and Cr display a weaker but still significant pattern of higher background within catchment 1 relative to the background sites. A single sample site in catchment 3 returned anomalous Cu and Pd (ashed-ICP) and a sample from the head of the Pebble Lake drainage system (site RAC-SS-5) returned an anomalous Pt value of 5.2 ppb.

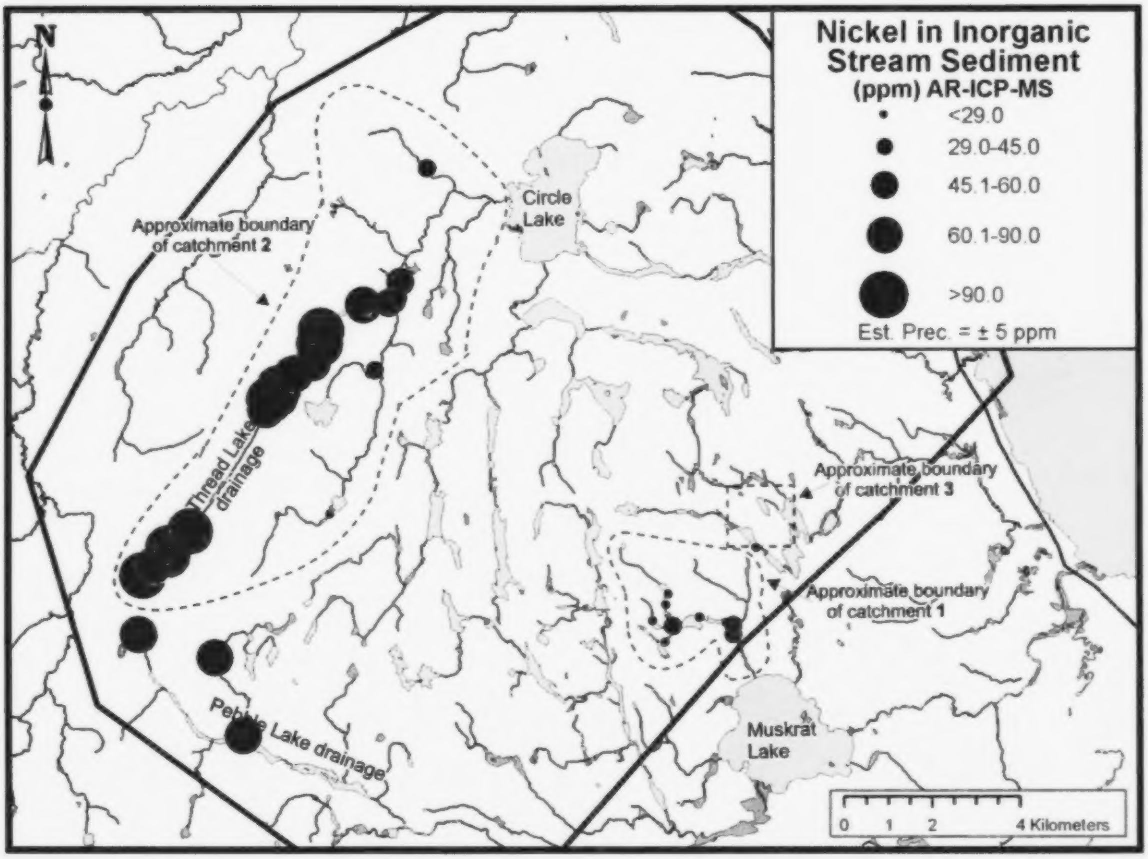


Figure 42. Nickel in inorganic stream sediment, Circle Lake study area.

Peat

A total of 9 organic peat samples were obtained: 3 from each of the anomalous catchments. Within catchment 2, one sample was obtained near Thread Lake and 2 were obtained in background areas. Compared to the Cheeseman Lake study area, the sampled peats, on average, have higher levels of Ni, Cr and Pt, approximately the same levels of Au and Pd, but lower Cu. Two of the highest Ni, Co and Pt (ashed-ICP and FA–ICP–MS) results came from samples that were observed to have some inorganic content (sites RAC-BOG-1 and RAC-BOG-4). The loss-on-ignition results (31% and 59%, respectively) for these samples indicate a significant inorganic component which may have influenced the metal results. The Ni by Enzyme Leach^{SM} results for RAC-BOG-1 were anomalous, however; at least some of the response is related to a loosely bound secondary phase and not just the inorganic clastic material.

The most significant metal responses in peat obtained from within the anomalous catchments compared to the 2 background sample sites are for Cu (ICP and EL), Pd (FA) and Au (INAA). Chromium and Co show no significant pattern or difference in levels between samples within anomalous catchments and those from background sites. Two sites, RAC-SS-51 and RAC-BOG-2 from catchments 3 and 1, respectively, returned very anomalous Cu levels (>550 ppm) and elevated Au (ashed-ICP and FA). Both of these sites are located near the outlet creeks of lakes with strongly anomalous Cu in lake sediment.

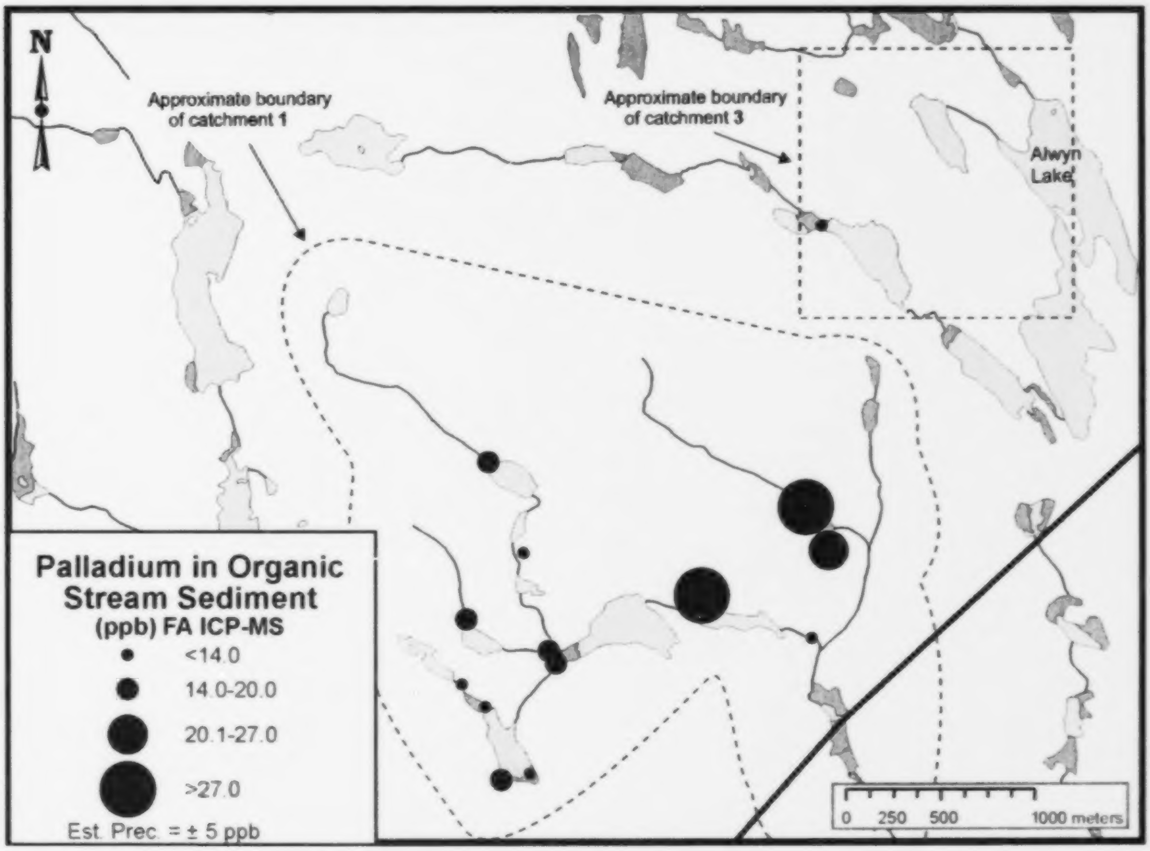

N
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Alwyn Lake
Palladium in Organic Stream Sediment
(ppb) FA ICP-MS
<14.0
14.0-20.0
20.1-27.0
>27.0
Est. Prec. = ± 5 ppb
0
250
500
1000 meters

Figure 43. Palladium in organic stream sediment, Circle Lake study area.

The average levels of Pd, Au and Cu in the peat samples from the Cheeseman Lake and Circle Lake study areas are much higher than at the Lac des Iles and Tib Lake study areas. This is due to several factors including the pervasive relatively high background of these elements in the diabase sills, the landscape conditions (rugged bedrock-dominated terrain), the strong weathering characteristics of the diabase and the mobility of these elements in the surficial environment.

Summary

The Circle Lake study area is a bedrock-controlled plateau underlain primarily by diabase sills. The surface of the plateau contains numerous depressions of various sizes that are commonly filled with lakes. The lakes are rimmed by a series of bedrock-controlled steps or escarpments some exceeding 30 m in height. The surface of the plateau is also cut by curvilinear to linear valleys likely controlled by fracture systems developed in the sills. Areas of highly weathered sill rocks (to depths exceeding 5 m) tend to occur along valley edges. These relationships suggest deeper weathering has occurred along fractures in the sills and that subsequent removal of the less cohesive weathered rock (residual soil) has produced the valleys. Talus covers the lower parts of many of the narrow steep-walled valleys in the area.

The results of the sampling project at the Circle Lake study area, similar to the Cheeseman Lake study area, demonstrate that significantly higher levels of the metals of interest are present and moving within the anomalous drainage catchments compared to background areas. The terrain is bedrock dominated and the dominant rock type in the west is a medium-grained, relatively fresh diabase.

Diamond drilling near Thread and Pebble lakes intersected 2 geochemically distinct diabase sills separated by an approximately 50 m thick unit of Sibley Group rocks (Wagner 2003). Lithogeochemical results from the drill core samples show that the upper sill has significantly higher levels of Ni and Pt than the lower sill. In the lower sill, the diabase becomes coarse grained and there is a marked increase in Pt, Pd, Au and Cu (but decreased Ni and Cr). This is analogous to the results of the surface bedrock sampling along the Thread Lake valley compared to the results from the eastern diabase samples. The available information from diamond drilling programs, which include several drill holes completed near the eastern boundary of the study area north of Muskrat Lake, suggests the western part of the study area has been displaced upwards relative to the east (*see* Figure 40). Therefore, the difference in geochemistry between the east and west may be related to natural variation within the upper diabase sill. The finer grained basal portion of this sill (with higher Ni and Pt) is exposed along the Thread Lake drainage; coarser grained diabase (with higher Cu and Pd), representing sill further from the chill margin with the Sibley Group, is present in abundance in the east part of the study area.

It is clear that the source of the Ni, Cu, Pd and Au anomalies determined in lake sediment within the Circle Lake study area are from the surrounding bedrock. The coarse-grained diabase, which has higher levels of Au, Cu and Pd than the medium-grained (and relatively "fresh") diabase, is present near the focal points of stream drainages with higher levels of these metals in stream sediment and water in the eastern catchments (1 and 3). Similarly, the diabase along the Thread Lake valley, which has higher Ni levels than the eastern diabase, has a spatial association with Ni anomalous lake sediments and the sampled surficial media. However, there are anomalous geochemical results that vector to several areas that may warrant further investigation (Figure 44). As discussed previously, in the "Summary" for the Cheeseman Lake study area (which, in many ways, is analogous to the Circle Lake study area), it is unclear if the intensity of these geochemical anomalies are due to a localized point source increase in mineralization; the effect of landscape (e.g., slope and/or relative lack of organics, which might otherwise act to "decouple" the geochemical bedrock signal from the lake basins); or due to local variations in weathering intensity (residual soils) of the diabase. Native Cu, as well as chalcopyrite, were observed in the lower diabase sill intersected by a diamond-drill hole near Thread Lake (Wagner 2003). In addition, as mentioned previously, Au levels up to 1 g/t in Nipigon sills have been documented (T.R. Hart, OGS, personal communication, 2005). Therefore, there is potential for the existence of localized point source mineralization that could account for the observed anomalous geochemistry.

The cover of till is thin and discontinuous in most of the anomalous catchment basin areas. The lengths of water flow-paths (surface and groundwater) in contact with bedrock and particularly residual soil in this setting is much greater than that in till. As a result, the contribution of the till to the anomalous trace element concentrations reported in lake sediment is probably minimal. Waters flowing in contact with the bedrock surface and through fractures and joints filled with loose granular residual soil most likely explain the lake sediment anomalies. Trace element values measured in residual soil samples could adequately explain the values obtained in the lake sediment geochemical survey.

Results from C-horizon till highlight areas where several of the concentrations of trace elements of interest were elevated. B-horizon anomalies tend to correspond to anomalies in C-horizon samples. The element anomalies found in humus sampled in the area all occur in soils developed in bedrock. Because of the large differences in element concentrations in C-horizon till and the bedrock, caution should be used not to discard lower concentrations of elements in humus or B-horizon samples developed in till in this area.

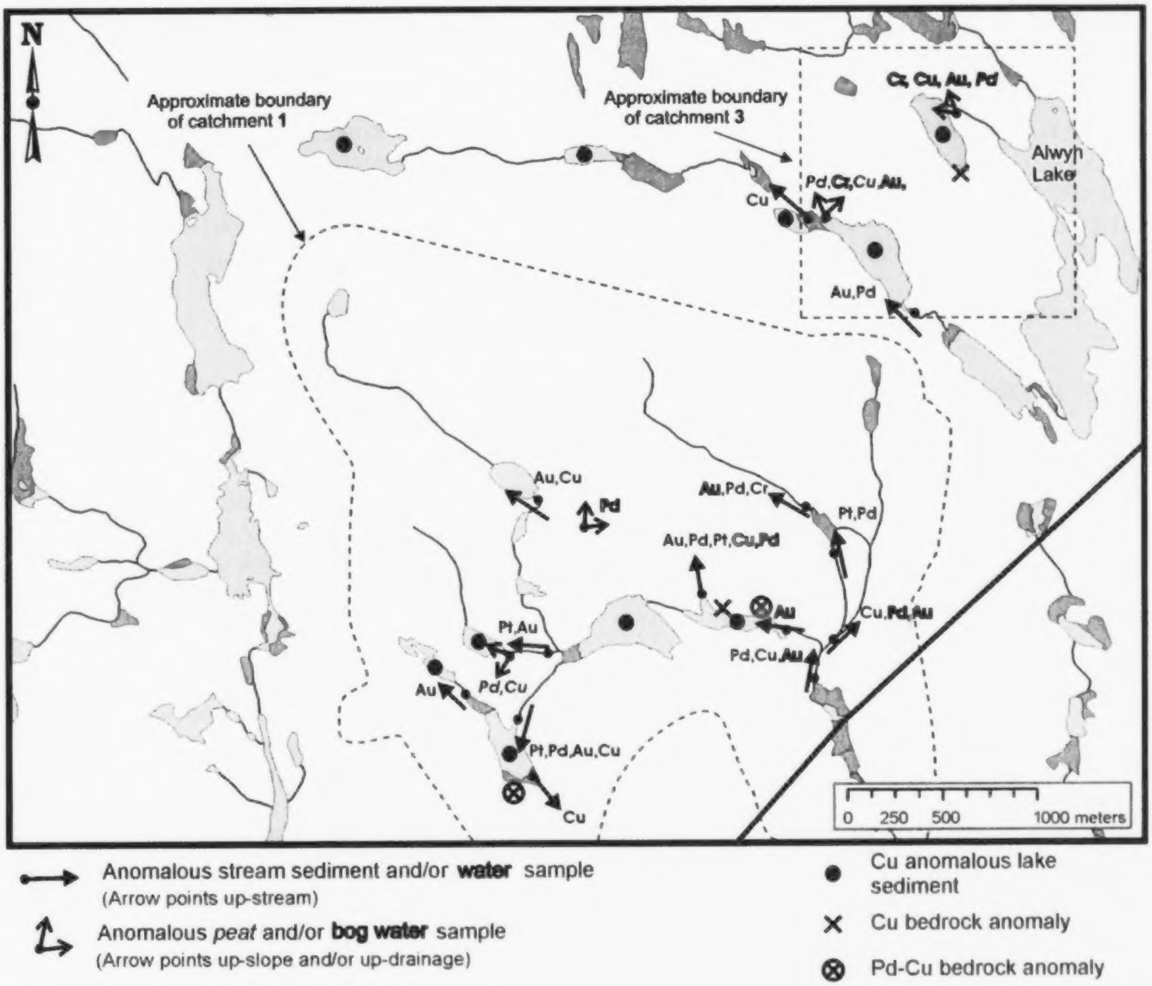

N
Approximate boundary of catchment 1
Approximate boundary of catchment 3
Cr, Cu, Au, Pd
Alwyn Lake
Pd,Cr,Cu,Au,
Cu
Au,Pd
Au,Cu
Pd
Au,Pd,Cr
Pt,Pd
Au,Pd,Pt,Cu,Pd
Au
Cu,Pd,Au
Pd,Cu,Au
Pt,Au
Pd,Cu
Au
Pt,Pd,Au,Cu
Cu
0 250 500 1000 meters
Anomalous stream sediment and/or water sample
(Arrow points up-stream)
Anomalous peat and/or bog water sample
(Arrow points up-slope and/or up-drainage)
Cu anomalous lake sediment
Cu bedrock anomaly
Pd-Cu bedrock anomaly

Figure 44. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, peat and stream sediments, Circle Lake study area.

TARRISON LAKES STUDY AREA

Introduction

Unlike the other 4 case study areas, the Tarrison Lakes case study area is not a bedrock-dominated terrain (Map 5, back pocket). The area is centred on the "Kaiashk Interlobate Moraine" of Zoltai (1965a), which is a large thick deposit of sand and gravel. Sediment associated with the moraine in the area of Badger Lake can exceed 80 m in thickness (Foster 2004). Bedrock is exposed both north and south of the moraine. A "scabland topography" is well developed on the bedrock surface north of the moraine and probably continues beneath it. It is possible that a large tunnel valley cut into bedrock occurs beneath the moraine in the vicinity of Badger Lake. There, a large part of the Nipigon sill(s) has been removed exposing Archean rocks along most of the valley floor. Several outliers of Nipigon sills remain along the valley floor.

Striations observed north of the moraine indicated a southward moving glacier and those east and south of the moraine indicate a westward moving glacier. Thus suggesting to Zoltai (1965a) a possible interlobate origin for this large sand and gravel-rich landform. Till was only observed beyond the limits of the moraine, however, it may be present beneath the moraine.

Based on field observations, the landform was supported by ice along its northern flank during formation. A zone of "oriented moraine" occurs along the northern ice-contact slope where the heavily crevassed ice margin was rapidly buried by stratified sediments being deposited by meltwater along the ice margin (crevasse fills). Deposition was occurring in a proglacial lake, possibly glacial Lake Agassiz, that inundated the recently uncovered area between 2 receding ice margins. The location of the eastern margin of a glacial lobe occupying the southern part of the Lake Nipigon basin is not known for certain, however, it may have been pinned up against the diabase sill at the eastern edge of the case study area. The "Kaiashk Interlobate Moraine" was probably an esker initially and, during ice marginal recession, the conduit widened and opened up to Lake Agassiz (?) waters as 2 ice lobes formed along the glacier margin. The upper part of the landform consists of coalescing ice-marginal deltas formed along the edge of the northern ice margin and is likely a correlative of the Lac Seul Moraine.

Numerous kettles and kettle lakes occur along the northern margin of the landform. The steep walls surrounding these lakes are composed of sand and/or gravel. Test pits, soil descriptions and sampling were done within the drainage basin of one kettle lake, Badger Lake, that had anomalous lake sediment concentrations of Pt and Pd (Photo 6). Two samples of till were also collected along the margins of the moraine.

Till: Glacial Dispersal

Till can not easily be used in the Tarrison Lakes area for mineral exploration. It is difficult to obtain C-horizon till samples within the moraine proper as thick extensive layers of sand and gravel form the surficial sediment. Till may be present at depth, however, it may have been eroded during moraine formation particularly during the initial esker-forming stage. Only 2 C-horizon till samples were collected; one from north and one southeast of the moraine.

HEAVY MINERAL RESULTS

Three samples, 2 till and one glaciofluvial sand, from the Tarrison Lakes area were processed by GeoLabs and analyzed for heavy minerals to obtain the overall heavy mineral assemblage in till from this area. The average heavy mineral composition consists of approximately 67% clinopyroxene, 9% calcic amphibole, 9% orthopyroxene, 4% olivine forsterite, 3% epidote and minor amounts (<2%) of fayalite, ilmenite and sub-calcic amphibole. These minor constituents can be of interest in mineral exploration (Averill 2001). The till sample collected north of the moraine, associated with southward striations, contained more epidote (8%) than the till sample collected on the southeast side of the moraine (1%) and about 13% less clinopyroxene grains.

In addition, 1 heavy mineral sample of glaciofluvial sand was processed and analyzed by Overburden Drilling Management Limited (ODM) of Nepean, Ontario. The results provided by ODM are contained in MRD 154.

Pigeonite dominated the heavy mineral assemblage recognized by ODM that also included epidote and diopside. No mineral grains containing platinum, palladium or gold were recovered. Two grains of forsterite, a possible kimberlite indicator mineral, were recovered and 5% of the assemblage were fayalite grains.

Photo 6. Badger Lake–Tarrison Lakes study area.

C-HORIZON TILL SAMPLE GEOCHEMICAL RESULTS

In this case study area, only 2 samples of till were collected. The till sample collected southeast of the moraine, associated with southwestward ice flow, contained more Cu than the till sample collected north of the moraine. The concentrations of the remaining elements of interest were essentially the same in both samples. The results are based on fire assay and ICP for PGEs and ICP for the other trace elements. A summary of the results is presented in Table 5. Results for all the geochemical analyses performed are contained in MRD 154.

Ice-Contact Sand and Gravel

A large body of sand and gravel referrred to as the "Kaiashk Interlobate Moraine" dominates the Tarrison Lakes study area. Associated with the moraine are a series of small kettle lakes, several of which returned anomalous Pd, Cr, Cu and Ni in an OGS lake sediment survey (Dyer and Russell 2002). The sediment surrounding one such anomalous kettle lake, Badger Lake, was sampled in detail with the aim of trying to understand and explain the lake sediment anomaly associated with the lake. Transport pathways of mineral and rock fragments in ice-contact stratified sediments are difficult to trace back to their source. Not only is there glacial transport, in this case from either the north or east-northeast, there is also meltwater transport. In the case of meltwater transport, it was either parallel to the main ridge during the esker stage or lateral or transverse to the ridge during the later ice-marginal deltaic stages associated with the formation of the Lac Seul Moraine. Up to 11% carbonate content was measured within of the –0.074 mm fraction of the ice-contact stratified sediments of the moraine. Rock fragments of the Sibley Group are believed to be the main source for the carbonate because they react to a dilute (10%) solution of HCl and they are quite abundant within the area of the moraine studied. Milled sand samples from the moraine contained up to 16% carbonate. The pH of lake water ranges from 6.3 to >8.2 along the moraine and is commonly >7 in the area of detailed study (Dyer and Russell 2002).

SAND AND GRAVEL: SOIL PROFILE GEOCHEMISTRY

Following deglaciation, the materials making up the land surface were exposed to weathering and soil-forming processes. The parent material (C-horizon) of the soil began to alter physically and chemically in response to these processes and other soil horizons formed. During this survey, the B-horizon of the mineral soil was sampled in addition to the relatively unaltered C-horizon or parent material. Humus, the organic part of a soil, developed from the accumulation of decaying plant residue (vegetation litter) was also sampled during this project.

The soils developed in sand and gravel in the Tarrison Lakes study area display a general decline in concentrations of Pt, Pd and Cu up through the soil profile from C-horizon through B-horizon to humus samples collected at the same sites. This relationship is similar to that obtained in the other case study areas that have soils developed entirely in till. This relationship falls into the Type 1, "leaching", profile, that is, a net downward increase in element concentration (Klassen 2003; *see* Figure 7). Nickel, Zn, Co and Cr had similar concentrations in the B- and C-horizon samples; the differences were commonly within the error of analytical measurement. Nickel, Co and Cr concentrations commonly decreased in the corresponding humus samples.

Gold, however, commonly showed the Type 2, "accumulation (surface)", geochemical profile type in soil profiles developed in sand and gravel from the case study area (*see* Figure 7). The Type 2 profile is a general decrease in element content up through the mineral soil horizons and an increase in the element concentration in the organic soil horizon (humus). Zinc also showed an increase in concentrations in humus samples. For these elements at this case study site, biological processes are the preferred mechanisms for enrichment in humus samples, rather than airborne contamination.

Platinum and Pd concentrations decrease between the various mineral soil horizons up soil profile. The soil profile geochemistry of Pt is similar to that of Pd. In general, Pt concentrations are less than Pd and the mobility or degree of decrease in concentration up the soil profile is less than Pd. Copper behaves similar to Pd being very mobile in soils at Tarrison Lakes. It is not uncommon to get a large reduction in Cu content from C-horizon to B-horizon samples. There is little change, however, in the concentration of Ni through the mineral soil horizons in sand and gravel, but, at many of the sites analyzed, the differences between the 2 horizons were within the error of analysis.

There was little to no removal of Ni, unlike Cu, in the B-horizon. Nickel does not appear to be as mobile in soil developed under the conditions at Tarrison Lakes. The solubility of Ni is inversely related to the pH (Kabata-Pendias and Pendias 1992). The higher carbonate content in the parent material of the soils at Tarrison Lakes, which is also indicated by the higher pH of the lakes in the area, is probably in part the cause of the lack of mobility. Results of the analysis of B- and C-horizon and humus samples are included in MRD 154.

Platinum, Pd, Ni and Cu concentrations were all anomalous in sample Tar-Soil 2001 collected about 300 m south of the kettle lake studied. The same 3 elements were also anomalous in the corresponding B-horizon sample (Tar-Soil-1001).

RESULTS OF HUMUS SAMPLING

Humus was only collected at a few of the sites where it was thick enough to sample. At these sites, the concentrations of most elements that were evaluated in the mineral soil horizons are generally lower in humus samples. The concentrations of Au and Zn are the exceptions. Platinum and Ni are the only 2 elements that occur at anomalous levels in the humus samples collected at the Tarrison Lakes area. They occur within the same sample, Tar-Soil-1002, collected about 175 m downslope of Tar-Soil 2001.

Lake Sediments

The Tarrison Lakes study area encompasses a number of Pd lake sediment anomalies that overly the Kaiashk Interlobate Moraine. The anomalous lakes in the northeast portion of the area were first sampled during the 1998 OGS Garden–Obonga lakes survey. Analysis of these samples by FA–ICP–MS for PGEs during the OTH program revealed several highly anomalous Pd values. These lakes were specifically resampled during the 2001 OGS Lac des Iles–Black Sturgeon River survey, which corroborated the earlier results. In addition to Pd, several of the lakes returned anomalous Cr, Cu and Ni. A small lake known as Badger Lake was selected for detailed follow-up by this project. In the most recent regional lake sediment survey, this lake returned anomalous Pd (47 ppb), As, Cr, Cu, Li and V.

Resampling of lake sediment, including both shallow and deep sediment, in Badger Lake was completed by boat. This is a deep lake (~15m), relative to its surface area. The sediment was noted to have a distinct H_2S odour and a black speckled appearance (likely amorphous Fe precipitates). The cause of the H_2S odour is likely due to anaerobic bacteria. Compared to the deep sediment, the shallow (surface) sediment returned higher levels of several elements including Pd (19.6 ppb), As, Cr and V. The Pd level at depth was 9.5 ppb. Such anaerobic conditions, with the attendant formation of H_2S, and the presence of alkaline water (surface water pH=8.5; pH measured at the bottom was 7.6), result in most metals partitioning into the sediment rather tnan staying in solution. This is corroborated by the very low base metal levels (except for Mo) determined in the water samples from this lake, even from 2 samples collected at depth near the bottom of the lake. However, the Pd results are quite high for lake water; of 7 lake waters sampled across the Tarrison Lakes study area, only Badger Lake water returned values above detection limit, ranging from 1 to 1.2 ppt. In addition, water sampled from a "lagoon" along the south shore of the lake returned the highest Au value (9.6 ppt) for a lake water in this study.

A series of small lakes along a drainage system that parallels the moraine to the southeast of Badger Lake were targeted for sampling during this project. Only one of the lakes was deemed suitable for sampling. Results indicated that only background levels of metals were present in both lake sediment and water from this site.

Lithogeochemistry

Four samples of rock from the Badger Lake area were collected and analyzed. A grab sample of fine-grained diabase was collected from a location approximately 60 m from the northeast shore of the lake. The sample was obtained from a relatively low-lying area in which a peat sample was also collected. It is unknown if this exposure is *in situ* bedrock or a boulder. This sample returned 13.9 ppb Pd, 12.6 ppb Pt, 148 ppm Cu, 72.2 ppm Co, 206.7 ppm Ni and 148.6 ppm Cr. Whole rock data, REE ratios and magnetic susceptibility measurements fall within the typical range for Nipigon diabase sills. Two diamond drill holes were completed in 2004 near Badger Lake by Gitennes Exploration Inc. One of the holes was abandoned in overburden, but the second, located approximately 400 to 500 m southwest of Badger Lake, intersected fine-grained diabase at a vertical depth of 30 m (Foster 2004). Almost identical lithogeochemistry results (including whole rock data) obtained by Gitennes Exploration for this diabase suggests the diabase sampled near Badger Lake may be outcrop or locally derived.

The 3 other rock samples were collected from the lake bottom of Badger Lake at a shallow spot on the eastern side of the lake. Although strongly weathered, they appear to be Sibley Group rocks and their lithogeochemical (REEs and major oxides) characteristics bear this out.

Hydrogeochemistry

Relatively high electrical conductivities and pH levels characterize this study area. Only 1 water sample (from a dug sump in peat) returned a pH value less than 7.0. The average of 49 water samples was 7.6; the most alkaline of the waters was lake water with an average of 7.9. As a consequence, most metals levels in Tarrison Lakes study area waters are very low. The exceptions are Mo, Pd and U. The average levels of Mo and U are higher in the Tarrison Lakes area waters than any of the other study areas likely, in large part, due to their mobility under alkaline conditions. Average levels of Pd in surface waters, with the exception of lake water from Badger Lake, are lower than all the other case study areas. However, waters obtained by piezometers around Badger Lake returned average levels of Pd twice as high as obtained at Lac des Iles by piezometers in bogs.

High electrical conductivities reflect high major element loadings to the waters; this is evident from the water analyses, which show very high levels of Ca, K and Mg.

GROUNDWATER

In order to sample groundwater entering Badger Lake, 10 piezometers were installed around the shore of the lake. This was done by boring down several tens of centimetres past the water table with a soil auger and then pushing the piezometer into place. The piezometers were emplaced to depths below surface ranging from 1 to 3.5 m, but, in all cases, the sampled water was from approximately 30 to 75 cm below the water table. At least 3 piezometer tube volumes were purged prior to obtaining a water sample for analysis and testing of pH and conductivity. Six of the piezometer installations were revisited, repurged and resampled between 1 to 3 days after the initial sampling. Five of the sites were resampled 1 year later in 2004. From the 2003 data, reproducibility is estimated as follows: Au ±0.3 ppt, Pd ±1.0 ppt, Pt ±0.2 ppt, Cu ±1.5 ppb, Ni ±1.5 ppb and Co ±0.15 ppb. Comparison of 2003 data versus 2004 data shows the same relative geochemical pattern (or site to site ranking) despite that, at some sites, the absolute values between duplicates exceeded the reproducibility estimates mentioned above. Because Cr was almost always below detection limit, an estimate of precision value is not possible. The piezometer water geochemical data indicates a higher flux of metals originating from the northeast and possibly southeast of Badger Lake. Elevated to anomalous results vectoring to both the northeast and southeast include the metals Ni (Figure 45), Co and Pt; the Au, Cu and Cr vectors point only to the northeast, and Pd points dominantly to the southeast. The median (1.2 ppt) and average (1.3 ppt) levels of Pd in Badger Lake groundwater are approximately twice the levels found in Lac des Iles groundwater obtained by piezometer.

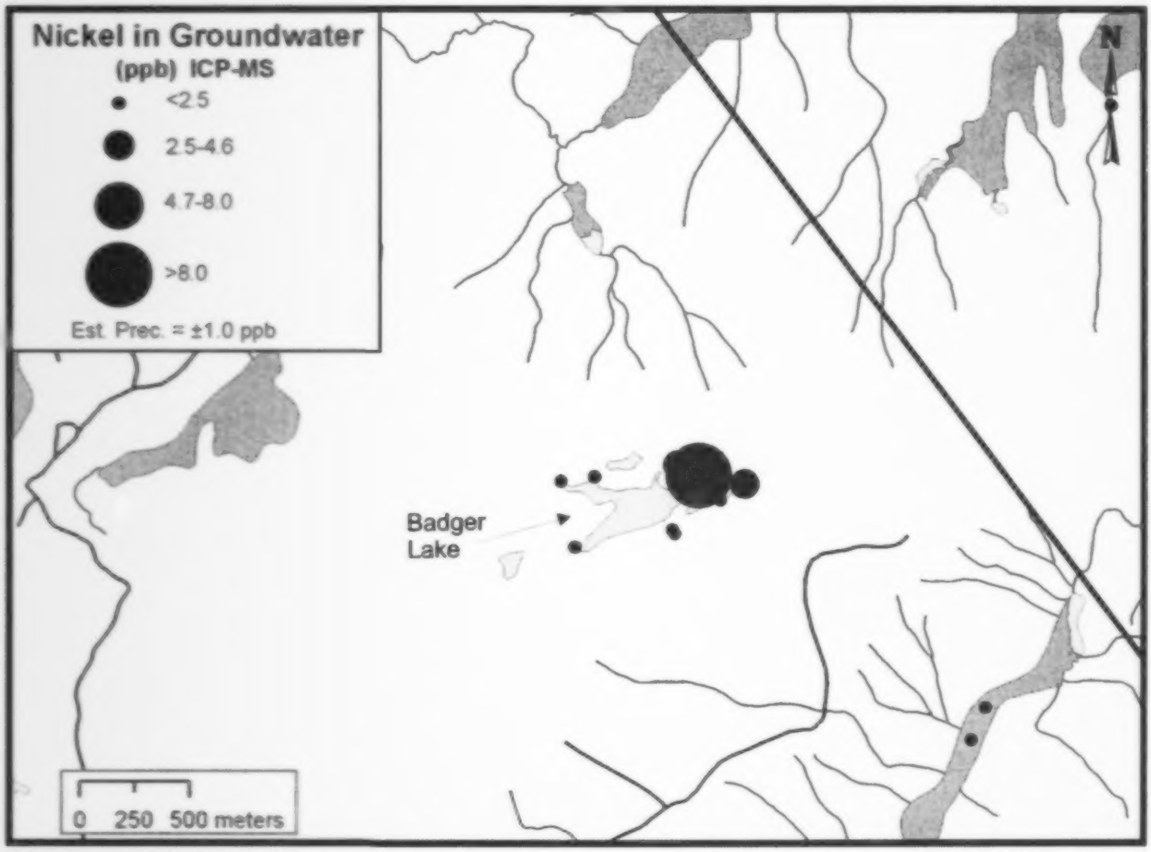


Figure 45. Nickel in groundwater, Tarrison Lakes study area.

BOG WATER

Bog water was obtained at 4 sites: 3 from the poorly drained low-lying area on the moraine flank and 1 from outside of the immediate area to the southwest near Highway 811. Dissolved metals in bog water are very low (Pd and Pt are below detection limit), typically <1 ppb; the lowest levels of all the case study areas. At site Tar-BOG-5, water was collected by dug sump and by piezometer for comparison. Levels of pH, conductivity, Cu, Sr and V were higher in sump water than the deeper piezometer water. Nickel was slightly higher in the deeper piezometer water, however, the difference did not exceed the estimate of precision.

STREAM WATER

Stream waters were collected from 13 sites in the study area. As with the bog waters, most dissolved metal levels in stream waters are very low in the Tarrison Lakes study area compared to the other study areas. For some elements (e.g., Ni), the range of data barely exceeds the estimate of precision. The highest Ni, Cu, Pt, and Au results came from site TAR-SS-2, the only inlet stream to Badger Lake. This stream is ephemeral and likely dominantly groundwater fed. Levels of these elements in stream water on the flanks of the moraine were low (6 sample sites on the northwest side and 5 on the southeast side of the moraine). Cobalt returned the highest values from the streams located to the northwest, draining areas off the moraine. The highest Pd levels (~1 ppt) occur at site TAR-SS-2 and from a stream to the northwest draining off the moraine. The significance of a value of 1 ppt is dubious because the estimate of precision for Pd was 1.2 ppt.

Sand

Samples of sand were collected at each site during the auguring of each hole for the piezometer installation. Only sand in contact with water (below the water table) was collected. For comparison, 4 samples of sand were also collected on the flank of the moraine to the southeast near the northeast-flowing drainage system. Two areas along the shore of Badger Lake have the highest levels of Ni (>44 ppm) and Co (>13 ppm) by AR-ICP–MS: 2 sites at the extreme northwest corner of the lake and 2 sites along the southeast shore. Copper and Cr do not show much variation in the sands around Badger Lake. The highest Cu and Cr results came from a site (TAR-GW-11) along the drainage system on the flank of the moraine. This site also returned the highest Pd value of 19 ppb. The sample at this site had the highest loss-on-ignition (LOI = 6.2%) of the sand samples, indicating some organic content compared to the other sand samples (average LOI of approximately 1.5%). The presence of organics may have biased the metals content of this sample due to complexing. At Badger Lake, the highest Pd value (7.2 ppb) in sand was from site TAR-GW-5 near the northeast shore. The range of Pt values was small (1.3 to 2.6 ppb); the highest value came from a site near the southeast shore of Badger Lake (Figure 46). No significant Au values were obtained. The elevated Ni and Co results in sand are coincident with the groundwater geochemistry that vector to the southeast of Badger Lake. All of the metals of interest are lower in the water table sands compared to the "C"-horizon sands collected around Badger Lake.

Peat

Accumulations of peat are virtually nonexistent around Badger Lake. Three samples were obtained, 2 of which have significant inorganic content (LOI ~24%), whereas the third sample more closely resembled humus and was collected only 5 to 15 cm below surface. Seven peat samples were obtained along the northeast-flowing drainage system on the southeast flank of the moraine. Probing with a soil auger revealed approximately 30 to 70 cm of peat overlying sand along this drainage system. One sample of peat was obtained well away from the Badger Lake area near Highway 811. This sample returned very low values for all metals and will not be discussed further.

The difference in character between the samples near Badger Lake and the samples on the flank of the moraine make comparison difficult. Potential sand contamination was a problem in both areas, and likely has contributed to the geochemical variation observed. For example, the initial sample collected at site Tar-BOG-11 (on the flank of the moraine) returned high levels of Cu, Ni, Co and Cr with LOI of 11.5%. Resampling in 2004, taking greater care to minimize sand (LOI of 38%), only replicated the Cr and Co levels. With this caveat in mind, the data show that, in general, a higher average level of Cr and Cu is contained in the organic samples overlying sand at Badger Lake. In addition, the dominant vector to source is to the northeast and east of the lake.

Anomalous Pd levels (>20 ppb) by FA–ICP–MS were obtained at the 2 sites along the southeast shore of Badger Lake and at 1 site on the flank of the moraine to the southeast. The Pd (FA) anomaly on the flank of the moraine (site TAR-BOG-11) was obtained only in the more organic-rich field duplicate collected in 2004. However, anomalous Pd by ashed-ICP was obtained in both the 2003 (lower LOI) and 2004 sampling at this location. These results conflict in terms of indicating whether LOI (inorganic content) is a controlling factor on Pd variation. However, the results are in agreement in terms of vectoring towards the southeast of Badger Lake.

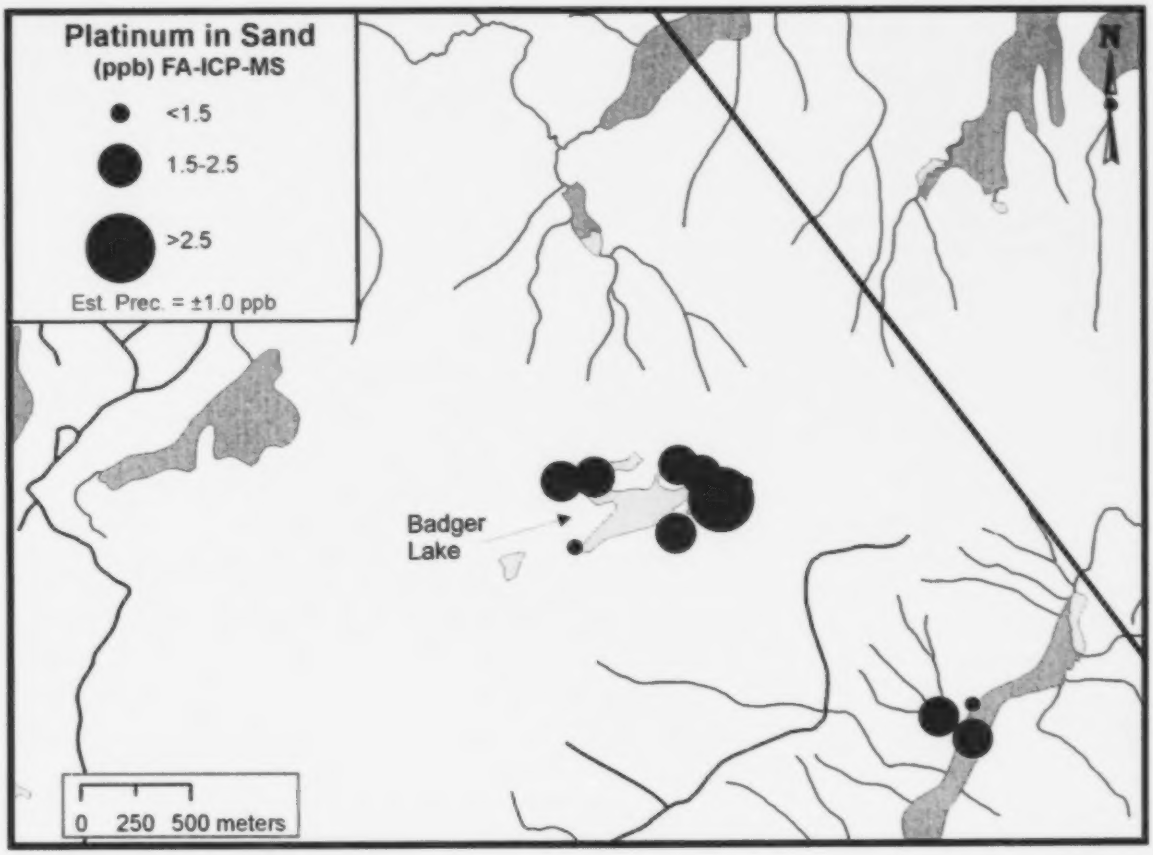


Figure 46. Platinum in sand, Tarrison Lakes study area.

Platinum results by FA–ICP–MS are low (<3 ppb). The lower LOI samples at Badger Lake returned slightly higher Pt. In general, there is no significant difference in Pt levels between the samples at Badger Lake and those on the morainal flanks. Only one Pt anomaly (16.6 ppb) by ashed-ICP–MS was obtained; this being TAR-BOG-1 located on the northeast shore of Badger Lake.

Gold analyses by ashed-ICP–MS and INAA are at low levels (<3.1 ppb) and no corroboration was apparent between the 2 methods. The only significant Au values by FA–ICP–MS (5 and 10 ppb) were obtained on the flank of the moraine, but were not duplicated by the other methods of Au analysis.

Nickel and Co results in peat by Enzyme Leach^{SM} show very little difference between Badger Lake and the moraine flank. The only anomalous Ni value came from the moraine flank (TAR-BOG-11), which was not replicated by the more organic (higher LOI) duplicate sample collected in 2004. Results for Cu were more interesting with 2 anomalous values near the northeast shore of Badger Lake indicating a northeast vector to source. The only Cu anomaly on the moraine flank, as the case with Ni, was not reproduced in the higher organic sample. This limited data suggests the existence of a loosely bound metals (Cu-Ni) phase related more to the inorganic (sand) fraction than the organic fraction.

Of the precious metals, Au (Enzyme Leach^{SM}) had 4 values above detection limit: 1 sample near the southeast shore of Badger Lake and 3 samples on the moraine flank. These data suggest the existence of a gold signal related to hydromorphic dispersion with a vector pointing to the southeast of Badger Lake.

Stream Sediments

Inorganic stream sediments were collected from 5 sites located northwest of Badger Lake (off the moraine), 8 sites off the moraine to the southeast and 1 site well away from the Badger Lake area to the southwest. Copper and Co results seem to vary randomly, showing no obvious pattern that can be related to a source. Copper results from one stream to the northwest of Badger Lake do seem to indicate more Cu originating from the moraine as compared to off the moraine. Nickel and Cr results are higher in the samples collected from the southeast side of the moraine. The range of Pt data is narrow (0.8 to 2 ppb) with the highest value from the stream sample located far to the southwest of the Badger Lake area. The Pd results are the most interesting: the 2 highest values (>5 ppb) occur on the northwest flank of the moraine and clearly demonstrate an origin from the stream coming off the moraine. Gold by FA returned no significant values, however, by INAA, 2 results greater than 5 ppb came from the drainage that flanks the southeast side of the moraine.

Summary

The Tarrison Lakes study area is centred on the “Kaiashk Interlobate Moraine,” a large thick deposit of ice-contact sand and gravel. The moraine is built over an irregular “scabland” topography of the bedrock surface with relief on the bedrock surface reported greater than 50 m (Foster 2004). Carbonate content within the stratified sediments is high compared to the till that occurs at surface away from the moraine in the study area and till in the other case study areas. The pH of the lakes here is also higher than in the other case study areas (Dyer and Russell 2002).

Platinum, Pd and Cu are mobile within the soil profiles. These elements are probably being transported to the lake by surface and groundwater. Nickel does not appear to be as mobile as these elements, possibly because of the higher pH levels. Nickel in the lake sediment sample from the lake studied was not anomalous, unlike samples from some of the nearby kettle lakes. An exploratory borehole encountered diabase beneath 30 m of moraine sediment south of Badger Lake within the detailed study area. Reported concentrations of Ni (145 to 193 ppm) were much higher than those encountered in the Cheeseman Lake area diabase. Copper content, however, was substantially lower (Foster 2004).

Anomalous concentrations for several elements occur in samples along the hill of sand and gravel south of Badger Lake. Sediment composing the hill could have originated from several directions. Paleocurrent measurements were not possible in this area due to the shallow nature of the exposures. It is recommended, however, that deeper exposures be temporarily opened in order that paleocurrent measurements can be taken.

Sand samples were collected below the water table during piezometer installations around Badger Lake. Average levels of Cr and Co in these samples are similar to the results from the sand samples obtained from along the drainage system on the southeast flank of the moraine. The average Ni (40 ppm) level obtained in the sands near Badger Lake is slightly higher than those from the moraine flank and is twice the average obtained from the Tarrison Lakes area inorganic stream sediments. Compared to the C-horizon sands collected around Badger Lake, all of the metals of interest have lower values in the water table sands. The lower average levels of Cu, Cr, Ni and Pd in the sands below the water table near Badger Lake may reflect original compositional differences or may be the result of continuous metal leaching by groundwater flowing toward Badger Lake. With the exception of Ni and Co, the levels of these metals in the lake sediment of Badger Lake are significantly higher than the average levels in the water table sands. However, the levels of Ni, Co and Cu are not uniform in the sands around Badger Lake; there are several sites with relatively high levels of Ni, Cu and Co, which serve to increase the average to a level not reflective of the majority of sand samples. These high Ni, Cu and Co results around Badger Lake are from sites at the northwest and southeast shores of the lake. The samples from the southeast shore are from the closest sites to the sample stations which returned the highest levels of metals obtained in the C-horizon sands.

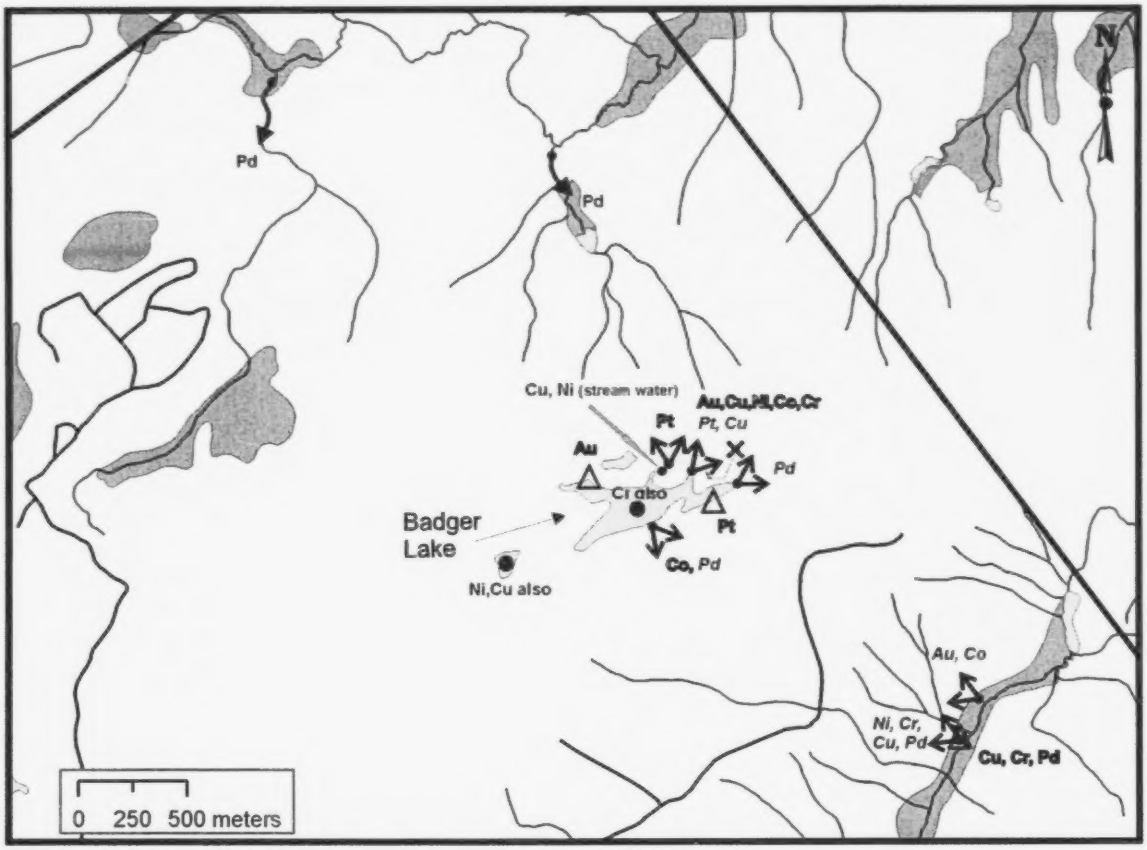
The presence of anaerobic conditions at the bottom of Badger Lake suggest that groundwater is not flushing the lake bottom; instead, relatively stagnant water conditions are present. This is probably a function of lake morphology (depth), which may be exacerbated by the presence of clay or bedrock at the lake bottom. The closest exploratory hole drilled by Gitennes Exploration Inc. was collared at 500 m asl, approximately 62 m above the lake level at Badger Lake. This hole was lost in overburden at a vertical depth of 80 m. This indicates that the bedrock surface could be at least 18 m (or more) below Badger Lake level. However, Badger Lake is approximately 15 m deep; therefore, the current bedrock surface could be within 3 m of the bottom of Badger Lake. Therefore, it is possible that the lake sediment anomalies are related to local bedrock. However, it is also possible that the anomalies are related to the leaching of metals from sediment (and boulders) that was transported from the north or northeast and potentially from a long distance.

Overall, the water and surficial media geochemical results at the Tarrison Lakes study area indicate a higher flux of metals coming from the northeast, east and southeast of Badger Lake (Figure 47). These vectors correlate with the highest levels of the metals of interest determined in the sand and gravel samples to the south of Badger Lake, and the possible diabase subcrop located to the northeast. The presence of vectors at only one side of the lake suggests that the lake sediment geochemistry at Badger Lake is not simply the product of leaching of metals from the surrounding morainal deposits. Rather, it is likely the product of a mixed geochemical signal originating from the northeast and southeast (from the morainal deposits and possible *in situ* bedrock), exacerbated by the limnological conditions of the lake.

SUMMARY OF CASE STUDY AREAS

During the Wisconsin Episode, the Laurentide Ice Sheet covered all case study areas. It was less than 10 000 years ago that the margin of the Laurentide Ice Sheet began to recede from the 5 case study areas.

There are indications from all but one case study area (Circle Lake) of multiple ice flow directions, however, only one till, related to the last ice flow direction, is commonly preserved. A warm or wet-based glacier that actively eroded the substrate and deposited subglacial till that reflects bedrock conditions in the up-ice flow direction overrode all areas. This condition is beneficial for mineral exploration programs using till. Exposures of multiple till layers or interbedded till and stratified sediments are common particularly on the down ice flow direction of bedrock knobs and ridges (lee-side cavity fills) and do not necessarily indicate multiple glaciations or ice flow directions.



● Pd-Pt anomalous lake sediment (other elements as indicated)

× Ni-Cr bedrock anomaly

⟶ Anomalous stream sediment and/or **water** sample

◁ Anomalous *peat* and/or **groundwater** sample

△ Anomalous **sand** sample

Figure 47. Geochemical anomaly ($\bar{x}+2\sigma$) vector map for water, sand, peat and stream sediments, Tarrison Lakes study area.

A major subglacial discharge of meltwater carved large steep-walled valleys and scabland topography in the bedrock surface before the area was deglaciated. It may have also removed deposits of older glacial events in the area.

Large proglacial lakes inundated all but the highest regions of the case study areas. The Lac des Iles and Tib Lake areas were partly submerged by the waters of glacial Lake Agassiz and the Tarrison Lakes area was entirely flooded. The Cheeseman Lake area was partly submerged by glacial Lake Minong of the Lake Superior basin and the Circle Lake case study area was entirely submerged by this lake and some of its ancestors. The landform referred to as the Kaiashk Interlobate Moraine probably formed initially within a conduit beneath the glacier (esker). Then, as the margins of the Laurentide Ice Sheet receded, it continued to form in a large proglacial lake (glacial Lake Agassiz) along the margin of a heavily crevassed ice lobe. The position of the lobe of ice in the Lake Nipigon basin prevented drainage of the proglacial lake eastward.

With further ice marginal recession, glacial Lake Minong waters inundated the Black Sturgeon River valley. Deep-water conditions caused washboard moraines (grounding line fans) to be formed along the receding ice margin, particularly in the Circle Lake area. Composed of a variety of sediment types, including subglacial lodgement till and flowtills, the washboard moraines may provide till sampling sites in areas where till is scarce. Glaciolacustrine sediments deposited within these proglacial lakes can hinder mineral exploration studies using till, by affecting sample location, density and sampling procedures. Till sampling in the Tib Lake case study area was affected by the distribution of thick glaciolacustrine sand deposits.

The 5 case study areas provide small windows on the glacial history of this potentially complex area. It is recommended that, to better understand the areas glacial history, regional systematic mapping of surficial geology be undertaken in the future.

From a geochemical exploration perspective, 4 of the 5 case study areas appear to be ideal situations to utilize postglacial surficial media to find prospective rocks, mineralization and/or to follow up lake sediment anomalies. Geochemical contrast is an important concept in the search for mineralization and prospective rocks. The mafic to ultramafic intrusions at the Lac des Iles and Tib Lake case study areas are surrounded by granitic rocks. This setting features an inherent geochemical contrast that is reflected in the geochemical results of most surficial media sampled during this project. The setting on the Nipigon Embayment is not as advantageous; significantly less geochemical contrast exists between the ubiquitous mafic sills and the ultramafic target rocks (e.g., "Seagull"-type intrusions). Therefore, the exploration strategy must focus on unique characteristics of the target rocks that would be reflected in the sampled surficial media (e.g., REEs, Mg, Cr).

In general, the geochemical intensity increases with increasing topographic relief in bedrock-dominated areas. Low relief bedrock-dominated areas have large drainage catchments and tend to have an erratic drainage network and significant organic (swamp) accumulations (e.g., Lac des Iles and Tib Lake areas). Low relief areas have less gravity potential to drive physical and/or hydromorphic processes. Effective (and available) sampling media are soils (developed in till), organic-rich media (lake sediments, organic stream sediments and peat) and water. Higher relief (higher energy) bedrock-dominated areas have smaller drainage catchments and tend to have a more definitive drainage network and less organic (swamp) accumulations (e.g., Circle Lake study area). Effective (and available) sampling media are soils (developed in till or highly weathered bedrock) and postglacial media such as organic lake sediment, organic and inorganic stream sediment and water. To some degree, the geochemical intensity in postglacial media from point sources of mineralization tend to be stronger in areas of more rugged (bedrock dominated) landscapes, particularly if there is less intervening organic media (swamps) to bind and intercept metals dispersion. This may be a significant variable to consider when interpreting geochemical data from areas with highly varied landscape conditions.

Despite the disturbance and contamination at the Lac des Iles mine site area, the methodologies and results from this study area (and from the Tib Lake area) can be used to help design, interpret and understand geochemical surveys over similar landscape conditions, particularly in areas underlain by Archean bedrock. The Cheeseman Lake and Circle Lake study areas differ somewhat in that the surveys were not centred on a known point source of mineralization. While various "vectors" to possible point sources were identified, what is lacking is a clear understanding of the geochemical footprint in the surficial environment caused by a known bedrock source on the Nipigon Embayment. For example, a case study survey conducted over the Seagull–Disraeli intrusions would have provided a framework to better understand, compare and interpret the results obtained in the Circle Lake and Cheeseman Lake study areas. Limited stream water sampling on and near the Seagull–Disraeli intrusions was carried out in 2004 under this project. The results (included in the sampled media summary below) indicate that these intrusions are imparting a very unique geochemical signal (much different from areas underlain by Nipigon diabase sills) to the surficial environment. It is recommended that a similar mapping and sampling program be carried out over the Seagull–Disraeli intrusions area in the future.

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Appendix 1

Geochemistry Summary Tables including Quality Control Data and Estimates of Precision

Humus

Element	Analytical Method	Units	MDL	Median	Range		Estimated	LKSD-4 (n=6)		
				(n=117)	Min	Max	Precision	Cert. Value	Mean	C.V.%
Co	Ashed ICP-MS	ppm	0.01	7.6	1.3	24.1	±3	11	10.9	18.4
Co	Enzyme Leach	ppb	1	71.0	14.0	325	±100	n/a	634	29.4
Cu	Ashed ICP-MS	ppm	1	20.2	5.5	776	±20	31	28.4	17.6
Cu	Enzyme Leach	ppb	1	54	12.0	4100	±15	n/a	197	26.0
Ni	Ashed ICP-MS	ppm	1	20.0	4.2	302	±14	31	40.0	21.1
Ni	Enzyme Leach	ppb	1	67.0	15.0	5820	±25	n/a	1097	22.3
Cr	Ashed ICP-MS	ppm	2	7.6	<2	145	±10	33	17.0	54.6
Cr	INAA	ppm	1	33.1	8.1	1109	±20	33	33.0	12.9
Cr	Enzyme Leach	ppb	3	<3	<3	198	±7	n/a	38.6	71.5
Au	Ashed ICP-MS	ppb	1	<1	<1	39.7	n/a	2	1.0	n/a
Au	FA-ICP-MS	ppb	1	2	<1	93	±3	2	2.2	43.7
Au	INAA	ppb	0.2	1.6	<0.2	48.1	±4	2	1.3	135.2
Au	Enzyme Leach	ppb	0.005	0.060	<0.005	0.410	±0.25	n/a	0.210	94.5
Pd	Ashed ICP-MS	ppb	1	1.6	<1	790	±5.0	n/a	1.6	155
Pd	FA-ICP-MS	ppb	0.1	2.1	<0.1	1280.0	±4	n/a	0.2	102
Pd	Enzyme Leach	ppb	0.5	<0.5	<0.5	5.1	n/a	n/a	<0.5	n/a
Pt	Ashed ICP-MS	ppb	0.1	1.8	<0.1	184.7	±20	n/a	0.9	135.7
Pt	FA-ICP-MS	ppb	0.1	1.3	<0.1	77.9	±1.5	n/a	0.3	61.7
Pt	Enzyme Leach	ppb	0.5	<0.5	<0.5	<0.5	n/a	n/a	<0.5	n/a

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 8 duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Ashed residue digested by aqua-regia prior to ICP-MS scan
6. Seven samples of reference material OGS-1 also included within the humus sample sequence

B- and C-Horizon

Element	Analytical Method	Units	MDL	Median (n=372)	Range		Estimated Precision	Till-1 (n=9)		
					Min	Max		Cert. Value	Mean	C.V.%
Co	AR-ICP-MS	ppm	0.1	15.6	7.5	174.6	**±1**	12	13.5	8.7
Cu	AR-ICP-MS	ppm	0.01	62.4	13.7	2220	**±10**	48	45.6	15.0
Ni	AR-ICP-MS	ppm	0.1	41.5	5.5	1990	**±10**	18	19.8	13.4
Cr	AR-ICP-MS	ppm	1	32.7	3.8	286.9	**±10**	30	30.6	17.0
Cr	INAA	ppm	5	83	17	662	**±20**	65	77.8	18.5
Au	FA-ICP-MS	**ppb**	1	2	<1	131	**±2**	13	15.8	79.4
Au	INAA	**ppb**	2	<2	<2	30	**±5**	13	17.3	144.9
Pd	FA-ICP-MS	**ppb**	0.1	2.9	<0.1	189.3	**±2.0**	n/a	0.1	306.7
Pt	FA-ICP-MS	**ppb**	0.1	2.8	<0.1	64.6	**±1.0**	n/a	0.2	255.0

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis (only performed on B horizon samples); AR = aquar-regia digestion
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 23 duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Fifteen samples of reference material OGS-1 also included within the B and C horizon sample batches

Sands

Element	Analytical Method	Units	MDL	Median (n=23)	Range		Estimated Precision	OGS-1 (n=4)		
					Min	Max		Accepted Value	Mean	C.V.%
Co	AR-ICP-MS	ppm	0.1	12.6	2.8	45.2	**±3**	n/a	32.3	4.5
Cu	AR-ICP-MS	ppm	0.01	52.0	19.2	251	**±8**	n/a	651	0.6
Ni	AR-ICP-MS	ppm	0.1	40.6	11.8	154	**±8**	n/a	1095	11.6
Cr	AR-ICP-MS	ppm	1	25.8	7.4	48.0	**±5**	n/a	47.2	2.4
Cr	INAA	ppm	5	70	15	129	**±15**	n/a	70.0	15.7
Au	FA-ICP-MS	**ppb**	1	1	<1	6	**±2**	11.8	5.7	12.6
Au	INAA	**ppb**	2	<2	<2	8	**±5**	n/a	10.8	100.0
Pd	FA-ICP-MS	**ppb**	0.1	6.8	2.9	23.3	**±2.0**	32.8	16.4	11.4
Pt	FA-ICP-MS	**ppb**	0.1	1.9	1.3	19.4	**±1.0**	29.7	13.8	176.0

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis; AR = aquar-regia digestion
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 10 analytical duplicate pairs and 5 field duplicate pairs (combined 2000 series and 5000 series duplicate pairs)
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. OGS-1 is an internal non-certified OGS standard

Peat

Element	Analytical Method	Units	MDL	Median (n=80)	Range		**Estimated Precision**	LKSD-4 (n=8)		
					Min	Max		Cert. Value	Mean	C.V.%
Co	Ashed ICP-MS	ppm	0.01	2.9	0.21	24.6	**±1**	11	9.2	9.5
Co	Enzyme Leach	**ppb**	1	26.5	2.7	221	**±15**	n/a	583.4	11.2
Cu	Ashed ICP-MS	ppm	1	70.8	1.1	997	**±20**	31	23.3	24.7
Cu	Enzyme Leach	**ppb**	1	126	4.7	1840	**±60**	n/a	180.9	10.2
Ni	Ashed ICP-MS	ppm	1	15.5	<1	178	**±8**	31	33.2	10.2
Ni	Enzyme Leach	**ppb**	1	70.9	4.4	628	**±40**	n/a	1066.9	13.2
Cr	Ashed ICP-MS	ppm	2	12.5	<2	152	**±5**	33	19.5	26.8
Cr	INAA	ppm	1	22	3	402	**±8**	33	35	9.3
Cr	Enzyme Leach	**ppb**	3	<3	<3	162	**±5**	n/a	29.3	102.4
Au	Ashed ICP-MS	**ppb**	1	1.3	<1	20.6	**±2.0**	n/a	1.4	362.6
Au	FA-ICP-MS	**ppb**	1	2	<1	38	**±3**	2	1.3	129.4
Au	INAA	**ppb**	0.2	2.8	<0.2	25.6	**±3.0**	2	3.2	95.1
Au	Enzyme Leach	**ppb**	0.005	<0.005	<0.005	0.072	**±0.03**	n/a	0.014	240.3
Pd	Ashed ICP-MS	**ppb**	1	<1	<1	34	**±5.0**	n/a	<1	n/a
Pd	FA-ICP-MS	**ppb**	0.1	8.3	<0.1	40.0	**±5**	n/a	0.14	132
Pd	Enzyme Leach	**ppb**	0.5	<0.5	<0.5	<0.5	**n/a**	n/a	<0.5	n/a
Pt	Ashed ICP-MS	**ppb**	0.1	1.1	<0.1	16.6	**±1.5**	n/a	1.0	285.7
Pt	FA-ICP-MS	**ppb**	0.1	0.8	<0.1	8.3	**±0.7**	n/a	0.21	79.0
Pt	Enzyme Leach	**ppb**	0.5	<0.5	<0.5	<0.5	**n/a**	n/a	<0.5	n/a

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 10 analytical duplicate pairs and 6 field duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Ashed residue digested by aqua-regia prior to ICP-MS scan
6. Five samples of reference material OGS-1 also included within the peats sample sequence

Inorganic Stream Sediment

Element	Analytical Method	Units	MDL	Median (n=93)	Range		Estimated Precision	LKSD-2 (n=4)		
					Min	Max		Cert. Value	Mean	C.V.%
Co	AR-ICP-MS	ppm	0.1	15.6	1.8	41.0	±3	17	13.4	13.7
Cu	AR-ICP-MS	ppm	0.01	57.2	1.6	684	±8	37	31.5	6.0
Ni	AR-ICP-MS	ppm	0.1	26.3	3.7	115	±5	26	21.7	6.5
Cr	AR-ICP-MS	ppm	1	15.8	1.0	117.4	±5	57	28.1	8.1
Cr	INAA	ppm	5	55	<5	789	±15	57	57	16.6
Au	FA-ICP-MS	ppb	1	3	<1	15	±2	3	2.4	26.3
Au	INAA	ppb	2	2	<2	23	±5	3	5.5	108.6
Pd	FA-ICP-MS	ppb	0.1	6.1	0.4	74.6	±2.0	n/a	0.4	16.6
Pt	FA-ICP-MS	ppb	0.1	3.8	0.7	16.3	±1.0	n/a	0.5	58.3

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis; AR = aquar-regia digestion
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 8 analytical duplicate pairs and 4 field duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Seven samples of reference material OGS-1 also included within the inorganic stream sediment sample sequence

Organic Stream Sediment

Element	Analytical Method	Units	MDL	Median (n=53)	Range		Estimated Precision	LKSD-2 (n=4)		
					Min	Max		Cert. Value	Mean	C.V.%
Co	Ashed ICP-MS	ppm	0.01	10.2	1.1	67.4	±11	11	11.9	117.6
Cu	Ashed ICP-MS	ppm	1	123.7	7.8	897	±100	44	53.5	96.3
Ni	Ashed ICP-MS	ppm	1	19.6	4.0	263	±15	16	16.7	31.1
Cr	Ashed ICP-MS	ppm	2	4.5	<2	120.6	±16	31	3.8	301.0
Cr	INAA	ppm	1	23	5	300	±10	31	30	3.8
Au	Ashed ICP-MS	ppb	1	<1	<1	771	±12	n/a	2.4	183.1
Au	FA-ICP-MS	ppb	1	3	<1	20	±2	5	9	225.3
Au	INAA	ppb	0.2	4.0	<0.2	18.4	±6	5	5.6	145.8
Pd	Ashed ICP-MS	ppb	1.0	2.7	<1	40.5	±6	n/a	<1	n/a
Pd	FA-ICP-MS	ppb	0.3	10.9	0.9	51.9	±5	n/a	0.5	125.8
Pt	Ashed ICP-MS	ppb	1.0	2.4	<1.0	15.1	±3.5	n/a	3.3	167.3
Pt	FA-ICP-MS	ppb	0.3	1.5	<0.3	8.8	±1.5	n/a	<0.3	n/a

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 8 analytical duplicate pairs and 7 field duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Ashed residue digested by aqua-regia prior to ICP-MS scan
6. Eight samples of reference material OGS-1 also included within the organic stream sediment sample sequence

Lake Sediment

Element	Analytical Method	Units	MDL	Median (n=31)	Range		Estimated Precision	OGS-1 (n=6)		
					Min	Max		Accepted Value	Mean	C.V.%
Co	AR-ICP-MS	ppm	0.1	11.5	3.3	52.3	**±1**	n/a	26.9	4.8
Cu	AR-ICP-MS	ppm	0.01	166	21.5	636	**±25**	n/a	587.3	3.5
Ni	AR-ICP-MS	ppm	0.1	25.1	13.6	111	**±8**	n/a	859.2	5.5
Cr	AR-ICP-MS	ppm	1	18	10.7	65.0	**±20**	n/a	47.9	4.4
Cr	INAA	ppm	1	26	13	78	**±10**	n/a	69	5.0
Au	FA-ICP-MS	**ppb**	1	3	<1	9	**±3**	11.8	9.6	54.1
Au	INAA	**ppb**	0.2	5.9	<0.2	17.8	**±5**	n/a	11.3	15.4
Pd	FA-ICP-MS	**ppb**	0.3	5.3	0.7	42.8	**±5**	32.8	16.9	91.1
Pt	FA-ICP-MS	**ppb**	0.3	1.7	0.7	23.3	**±0.6**	29.7	26.0	88.7

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish; INAA= Instrumental Neutron Activation Analysis; AR = aquar-regia digestion
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 12 analytical duplicate pairs and 6 field duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. OGS-1 is an internal non-certified OGS standard
6. Two samples of reference material LKSD-4 were also included within the lake sediment sample sequence

Rock

Element	Analytical Method	Units	MDL	Median (n=110)	Range		Estimated Precision	TDB-1 (n=8)		
					Min	Max		Cert. Value	Mean	C.V.%
Co	ICP-MS	ppm	0.1	55.4	1.1	152.6	**±20**	47	51	16.8
Cu	ICP-MS	ppm	0.2	171	5.2	3960	**±40**	323	330	22.1
Ni	ICP-MS	ppm	0.5	80.3	4.1	2740	**±30**	92	105	8.4
Cr	ICP-MS	ppm	0.5	51.7	6.9	848	**±20**	251	182	13.8
Au	FA-ICP-MS	**ppb**	1	4	<1	313	**±3**	6	6	38.4
Pd	FA-ICP-MS	**ppb**	0.1	16.5	<0.1	977.9	**±5**	22.4	21.9	7.1
Pt	FA-ICP-MS	**ppb**	0.1	6.2	<0.1	245.6	**±1.0**	5.8	4.6	17.9

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; FA-ICP-MS= Fire Assay/ICP-MS finish
2. MDL = method detection limit
3. Estimated precision at 95% confidence level; based on results of 9 analytical duplicate pairs
4. C.V.% = coefficient of variation at two standard deviations (95% confidence level)
5. Five samples of reference material OGS-1 and six samples of reference material LDI-1 were also included within the rock sample sequence

Water

Element	Analytical Method	Units	MDL	Median (n=350)	Range		Estimated Precision[1]	Estimated Precision[2]	SLRS-4 (n=18)		
					Min	Max			Cert. Value	Mean	C.V.%
As	ICP-MS	ppb	0.02	0.37	0.08	2.41	**±0.12**	**±0.12**	0.68	0.73	8.6
Au	HR-ICP-MS	**ppt**	0.2	<0.2	<0.2	20.5	**±0.4**	**n/a**	n/a	0.9	71.3
Ce	ICP-MS	ppb	0.0003	0.1608	0.0034	7.501	**±0.1**	**±0.06**	n/a	0.35	6.7
Co	ICP-MS	ppb	0.005	0.161	<0.005	9.65	**±0.12**	**±0.04**	0.033	0.028	9.6
Cr	ICP-MS	ppb	0.5	<0.5	<0.5	14.5	**±0.5**	**±0.9**	0.33	0.59	141.4
Cu	ICP-MS	ppb	0.2	3.4	<0.2	148.6	**±1.5**	**±0.3**	1.81	1.83	5.4
Fe	ICP-MS	ppb	0.3	384.8	18.6	5020.0	**±70**	**±100**	103	98.4	6.6
Gd	ICP-MS	ppb	0.001	0.034	<0.001	0.742	**±0.014**	**±0.008**	n/a	0.043	14.6
Ir	HR-ICP-MS	**ppt**	0.2	<0.2	<0.2	3.4	**±0.21**	**n/a**	n/a	0.1	51.4
La	ICP-MS	ppb	0.0003	0.12	0.0031	4.29	**±0.06**	**±0.04**	n/a	0.28	5.4
Mn	ICP-MS	ppb	0.07	13.1	0.13	1760	**±14**	**±3.5**	3.37	3.43	5.6
Na	ICP-MS	ppb	0.3	1425	180.1	59200	**±400**	**±350**	2400	2288	12.1
Ni	ICP-MS	ppb	0.3	1.1	<0.3	62.5	**±1.5**	**±0.8**	0.67	0.66	11.0
Pb	ICP-MS	ppb	0.01	0.09	<0.01	12.70	**±0.36**	**±0.50**	0.086	0.076	57.9
Pd	HR-ICP-MS	**ppt**	1	<1	<1	24	**±1.2**	**n/a**	n/a	<1	n/a
Pt	HR-ICP-MS	**ppt**	0.1	0.12	<0.1	89.4	**±0.1**	**n/a**	n/a	1.0	8.5
Rh	HR-ICP-MS	**ppt**	1	<1	<1	9.1	**±0.6**	**n/a**	n/a	<1	n/a
Ru	HR-ICP-MS	**ppt**	1	<1	<1	5.4	**±1.9**	**n/a**	n/a	<1	27.6
Sb	ICP-MS	ppb	0.01	0.03	<0.01	0.17	**±0.02**	**±0.04**	0.23	0.25	4.8
Sc	ICP-MS	ppb	1	1.1	<1	4.9	**±1.4**	**±0.65**	n/a	<1	n/a
Si	ICP-MS	ppb	0.01	5650	572.8	24400	**±1100**	**±1000**	n/a	2111	12.6
Sm	ICP-MS	ppb	0.001	0.032	<0.001	0.746	**±0.014**	**±0.008**	n/a	0.062	11.2
U	ICP-MS	ppb	0.002	0.013	<0.002	1.914	**±0.4**	**±0.005**	0.050	0.045	11.6
Zn	ICP-MS	ppb	0.5	1.2	<0.5	37.3	**±5.5**	**±3.5**	0.93	0.92	80.9

Notes:

1. ICP-MS = Inductively Coupled Plasma Mass Spectroscopy; HR = High-Resolution
2. MDL = method detection limit
3. Estimated precision[1] at 95% confidence level based on results of 28 field duplicate pairs
4. Estimated precision[2] at 95% confidence level based on results of 18 analytical duplicate pairs
5. SLRS-4 = National Research Council, Saint Lawrence River Standard #4: certified reference standard
6. C.V.% = coefficient of variation at one standard deviation (68% confidence level)

Metric Conversion Table

Conversion from SI to Imperial			Conversion from Imperial to SI		
SI Unit	*Multiplied by*	*Gives*	*Imperial Unit*	*Multiplied by*	*Gives*
			LENGTH		
1 mm	0.039 37	inches	1 inch	**25.4**	mm
1 cm	0.393 70	inches	1 inch	**2.54**	cm
1 m	3.280 84	feet	1 foot	**0.304 8**	m
1 m	0.049 709	chains	1 chain	20.116 8	m
1 km	0.621 371	miles (statute)	1 mile (statute)	**1.609 344**	km
			AREA		
1 cm^2	0.155 0	square inches	1 square inch	**6.451 6**	cm^2
1 m^2	10.763 9	square feet	1 square foot	**0.092 903 04**	m^2
1 km^2	0.386 10	square miles	1 square mile	2.589 988	km^2
1 ha	2.471 054	acres	1 acre	0.404 685 6	ha
			VOLUME		
1 cm^3	0.061 023	cubic inches	1 cubic inch	**16.387 064**	cm^3
1 m^3	35.314 7	cubic feet	1 cubic foot	0.028 316 85	m^3
1 m^3	1.307 951	cubic yards	1 cubic yard	0.764 554 86	m^3
			CAPACITY		
1 L	1.759 755	pints	1 pint	0.568 261	L
1 L	0.879 877	quarts	1 quart	1.136 522	L
1 L	0.219 969	gallons	1 gallon	**4.546 090**	L
			MASS		
1 g	0.035 273 962	ounces (avdp)	1 ounce (avdp)	28.349 523	g
1 g	0.032 150 747	ounces (troy)	1 ounce (troy)	**31.103 476 8**	g
1 kg	2.204 622 6	pounds (avdp)	1 pound (avdp)	**0.453 592 37**	kg
1 kg	0.001 102 3	tons (short)	1 ton (short)	**907.184 74**	kg
1 t	1.102 311 3	tons (short)	1 ton (short)	**0.907 184 74**	t
1 kg	0.000 984 21	tons (long)	1 ton (long)	**1016.046 908 8**	kg
1 t	0.984 206 5	tons (long)	1 ton (long)	**1.016 046 90**	t
			CONCENTRATION		
1 g/t	0.029 166 6	ounce (troy)/ ton (short)	1 ounce (troy)/ ton (short)	34.285 714 2	g/t
1 g/t	0.583 333 33	pennyweights/ ton (short)	1 pennyweight/ ton (short)	1.714 285 7	g/t

OTHER USEFUL CONVERSION FACTORS

	Multiplied by	
1 ounce (troy) per ton (short)	31.103 477	grams per ton (short)
1 gram per ton (short)	0.032 151	ounces (troy) per ton (short)
1 ounce (troy) per ton (short)	20.0	pennyweights per ton (short)
1 pennyweight per ton (short)	0.05	ounces (troy) per ton (short)

Note: Conversion factors which are in bold type are exact. The conversion factors have been taken from or have been derived from factors given in the Metric Practice Guide for the Canadian Mining and Metallurgical Industries, published by the Mining Association of Canada in co-operation with the Coal Association of Canada.

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